Arctic Climate Issues 2014: Short-Lived Climate Pollutants and the Arctic: What We Know, What We Can Do - Policy-makers Summary

Introduction

The main cause of recent climate change is well known: increased anthropogenic emissions of carbon dioxide around the world. Carbon dioxide is by far the largest single driver, is released in vast quantities by human activities, and stays in the atmosphere for centuries or longer, which means its warming effects persist for that long as well. Carbon dioxide also leads to ocean acidification. Action to reduce emissions of carbon dioxide is the essential backbone of any climate change mitigation strategy.

But other substances contribute, too. Short-lived climate pollutants (SLCPs) are gases and particles that cause warming and have lifetimes in the atmosphere of a few days to a decade, much shorter than that of carbon dioxide. The shorter the lifetime, the more quickly atmospheric concentrations can be reduced by lowering emissions. This means that policy action can provide climate mitigation benefits in the short term, slowing the rate of warming and its consequent impacts over the next decades. Human activities have caused increased air concentrations of the SLCPs methane, black carbon, and ozone, affecting both global and Arctic climate. Reductions of these SLCPs can be an important complement to mitigation of carbon dioxide.

Previous work [name the reports or the years] by the Arctic Council's Arctic Monitoring and Assessment Programme (AMAP) has examined the climate impacts of three SLCPs: methane, black carbon, and ozone. Those reviews and analyses described their role in Arctic climate warming, and found that they could potentially make a large contribution to Arctic warming. There remained, however, considerable uncertainty regarding the specific processes by which they influence Arctic climate and the amount of warming for which they are responsible.

These efforts led to the creation of two AMAP expert groups to carry this work further, one focusing on methane and one on black carbon and ozone. The technical reports [titles] recently completed by these expert groups have used new observational data and modelling to provide an authoritative and up-to-date review of current understanding of the climate impacts of these SLCPs. The purpose of these reports is to provide the scientific foundation to inform Arctic States and provide a basis for their actions to reduce the atmospheric levels of the three SLCPs and thus their warming effects in the Arctic. While much remains to be learned, these new analyses have enabled an estimation of how SLCP mitigation can affect Arctic warming, pointing to a role for SLCP mitigation in parallel with efforts to mitigate carbon dioxide. They have also better identified major emission sources and source areas of the substances, including the relative roles of Arctic States in regional and global emissions.

In addition to their role in climate, some SLCPs affect air quality, with negative effects on public health, agriculture, and ecosystems. The sources of SLCPs are often the sources of other pollutants, which have their own impacts on air quality and health. Effects on health and ecosystems give important additional benefits to SLCP mitigation. These, however, are outside the scope of the current work, which, like the technical reports on which it is based, focuses on impacts to Arctic climate.

This document presents a brief summary of the main findings of the technical reports, which are the basis for the information presented here. In addition, this document contains conclusions drawn by the AMAP Working Group in response to the information presented in the technical reports. These conclusions were developed by the AMAP Working Group, not the scientists who prepared the technical reports.

What are SLCPs?

The term short-lived climate pollutants (SLCPs) refers to a group of greenhouse gases and particulates that remain in the atmosphere for a few days to a decade and have warming effects on climate. The Arctic Council has focused its SLCP work on methane, black carbon, and ozone. These three substances in general come from different sources and behave differently in the atmosphere. This report thus treats them individually rather than as a group.

Although considerable progress has been made in recent years, our understanding of the role of the three SLCPs in Arctic climate change is limited by:

- our ability to measure black carbon in air and also on snow and ice,
- the difficulty of extrapolating air concentrations across the Arctic on the basis of the limited number of Arctic measurement sites,
- uncertainties in global and regional emissions and subsequent transport,
- our knowledge of the physical, biological, and chemical processes that influence levels of these substances in the atmosphere, and
- the challenges of modelling the Arctic climate response to the complex atmospheric processes associated with SLCPs, as well as ecosystem processes specific to methane.

Despite these knowledge gaps, and based on current scientific understanding, **there is confidence that, collectively, these three SLCPs play a role in both Arctic and global warming, and that measures to address them using existing technologies can be effective and produce beneficial results quickly**. For these reasons, the study of methane, black carbon, and ozone is important.

<u>Methane</u>

Methane, like carbon dioxide, is a greenhouse gas. It is the main component in natural gas. A given quantity of methane has a warming influence many times more potent than the same amount of carbon dioxide. Methane stays in the atmosphere for about nine years before it is broken down into other compounds. The nine year lifetime allows methane to be mixed throughout the global atmosphere. Despite a much lower emission rate than that of carbon dioxide, **methane is the second most important anthropogenic contributor to current global warming**.

Black Carbon

Black carbon, or soot, is a tiny, solid particle that absorbs solar radiation, thereby warming the atmosphere. It is co-emitted with and interacts in the atmosphere with various other pollutants, some of which cause cooling. Black carbon typically stays airborne for about a week. Because this time is so short, its concentrations are highest close to its sources. Nonetheless, black carbon in itself is a major contributor to current global warming, following carbon dioxide and methane. In addition to its effects on atmospheric warming, black carbon that is deposited on snow or ice can cause surface warming and melting by absorbing solar radiation to a much greater degree than pristine ice or snow. In the Arctic, **this warming effect is particularly strong in spring when the snow is melting and longer days mean more sunlight**.

Ozone

Ozone, like methane, is a greenhouse gas. It is a secondary pollutant, meaning that it is formed through reactions involving other pollutants in the air, including methane, and sunlight. Ozone remains in the atmosphere for weeks to months on average, allowing it to be transported long distances although it does not become sufficiently well mixed (as methane does) to achieve near-uniform global concentrations. The pollutants that react to produce ozone, called ozone precursors, are found throughout the atmosphere, meaning that ozone itself is produced throughout the world, including in the Arctic. **The main concern for warming, therefore, is ozone concentrations in the lower atmosphere, or troposphere**.

What sources release SLCPs?

Methane, black carbon, and ozone all come both from natural processes and from human activity. The three substances are sometimes related by source type and region and by interactions and transport in the atmosphere. Nonetheless, they are best considered separately in terms of their main sources.

Methane

Because it is well mixed throughout the atmosphere, sources of methane throughout the world influence Arctic climate, in addition to both anthropogenic and natural sources in the Arctic.

Anthropogenic methane emissions result primarily from the production and use of fossil fuels and to a lesser degree waste and agriculture. Sources of methane related to fossil fuels include venting and flaring at oil and gas fields, loss during the transport of natural gas, coal mining, and incomplete combustion. The oil and gas sector accounts for about a third of global anthropogenic emissions. Major biological sources include decomposition in landfills, water and wastewater treatment, agricultural fires, rice cultivation, and livestock digestion. Water and wastewater treatment account for about one fifth of global emissions, and biomass burning produces a tenth or less, depending on which types of burning are included. Atmospheric levels of methane have more than doubled since 1750 and have continued to rise since observations were first made. Arctic Council States account for about one fifth of global emissions, mostly from Russia and the United States.

Natural methane emissions result from the decay of organic matter in the absence of oxygen, as can occur in waterlogged soils and in lakebeds. **On land, wetlands are the main natural source of methane emissions***.* This is particularly relevant to the Arctic, where thawing permafrost may expose large reservoirs of previously frozen organic matter to decay or decomposition, potentially resulting in increased natural methane emissions.

At sea, methane is released from ocean sediments, especially those containing gas hydrates. There continues to be large uncertainty in estimates of how much methane is stored in these marine environments. Further, most methane released from the seabed is consumed by bacteria in the ocean before it reaches the air, though in shallow seas there is the potential for larger releases to the atmosphere as methane bubbles reach the surface more quickly. Thawing of subsea permafrost can accelerate the rate of release, but methane releases from the Arctic Ocean are not expected to rise sharply in the near future.

Black Carbon

Black carbon comes from incomplete combustion of fossil fuels and biogenic fuels, such as wood. Forest fires are the main natural source of black carbon. Human activity, however, is a larger source at a global level, though difficulties in measuring black carbon mean that there are considerable uncertainties in global emissions estimates for both natural and anthropogenic sources. **Ground transportation and residential and commercial use of fossil and biogenic fuels account for most black carbon emissions in Arctic countries and worldwide**. The energy sector is also a substantial source in Arctic States. About three-quarters of energy sector emissions are from flaring. Arctic States account for about one tenth of global anthropogenic emissions of black carbon.

Because the location of black carbon sources determines the likelihood of transport to the Arctic, a breakdown of emissions by latitude is important. At present, East and Southeast Asia account for about two-fifths of the black carbon that reaches the Arctic, due to the quantity of their emissions. Russia, largely because of its proximity to the Arctic, accounts for a further fifth of Arctic black carbon. Gas flaring in Russia is a particularly significant contributor.

While only about one percent of global anthropogenic emissions occur north of 60°N, and only a tenth of that comes from sources north of 70°N, black carbon emissions from Arctic States have greater impacts because they are closer to the Arctic. Within the Arctic, shipping currently accounts for about 5% of black carbon emissions, but could double by 2030 and quadruple by 2050 under some projections of Arctic vessel traffic. Flaring of excess natural gas at oil and gas fields, an alternative to releasing methane straight to the atmosphere, accounts for two-thirds of Arctic emissions of black carbon, and typically also results in emissions of methane from incomplete combustion.

There is strong evidence that black carbon in Arctic air decreased from 1993 to 2011, perhaps by as much as half. Trends on snow are harder to determine than trends in air because data are sparse. Emissions are not expected to increase greatly worldwide in the coming decades, and could decrease further with the use of available technology.

Ozone

Tropospheric ozone occurs in the Arctic largely in proportion to Northern Hemisphere emission levels of ozone precursors, the pollutants (including methane) that react in the air to create ozone. **East and Southeast Asia and the United States emit the most anthropogenic ozone precursors and thus have the largest effects on ozone levels in the Arctic**. Ozone precursors come from natural sources as well as from human activity. Forest fires in northern areas are important natural sources as they are nearby and likely have a significant impact on Arctic ozone levels in summer. Increased Arctic shipping may also result in more local ozone production.

There is some evidence that ozone levels in the lower atmosphere are increasing in the Arctic, but results vary greatly by the location and time period over which ozone has been monitored.

How do SLCPs affect the Arctic?

SLCPs are all transported to and within the Arctic by the atmosphere. **Methane, black carbon, and ozone affect the Arctic climate both by warming the Arctic directly and by increasing overall global warming, which indirectly contributes to Arctic warming.**

Methane

Climate models indicate that **the rise in global methane concentrations in the air since pre-industrial times has increased Arctic temperatures by about half a degree C to date**, about twice as large as its impact on global temperature. This difference is consistent with the faster rate of Arctic warming overall, known as Arctic amplification of climate change. During winter, there is atmospheric transport of methane to the Arctic from mid-latitude regions. During the summer, concentrations are more variable and include the influence of emissions from Arctic wetlands. Though rising temperatures are expected to increase emissions from natural ecosystems, this effect has not been detected in Arctic atmospheric methane concentrations. Because methane is well mixed throughout the global atmosphere, emission reductions anywhere in the world can contribute to reducing Arctic warming from this SLCP.

Black Carbon

Black carbon (not including co-emitted pollutants) has warmed the Arctic by an amount comparable to methane, although the uncertainty for black carbon is much larger than for methane. Because black carbon has different effects depending on its altitude in the atmosphere, the locations of black carbon sources and the details of its transport pathways are important considerations. Black carbon at high altitudes in the Arctic leads to surface cooling.. Black carbon found lower in the atmosphere, leading to surface warming and at times ending up on snow and ice, tends to come from northern sources. Black carbon concentrations in the lower atmosphere in the Arctic tend to be highest in winter and spring, when there is typically a stable zone of cold, dense air over the Arctic. In general, the farther north the source, the lower in the Arctic atmosphere the particles will occur, and the greater their warming effects. Thus, **emissions from Arctic States are responsible for about a third of black carbon’s warming effects in the Arctic**, largely from direct effects of black carbon in the region, including enhanced melting of ice and snow. The other two-thirds come primarily from black carbon emissions outside Arctic countries that raise global temperature and thus affect the Arctic indirectly. The global effects of black carbon suggest a need for global action, and the high impact of northern sources on Arctic snow and ice suggest a similar need for action within the Arctic countries themselves.

Ozone

Tropospheric ozone from anthropogenic pre-cursors has a smaller impact on Arctic temperature than either methane or black carbon. Ozone also raises different concerns depending on its altitude. Surface levels appear to be influenced primarily by pollution from Europe. Ozone higher up in the troposphere is more important for warming, and levels here are affected more by North American and Asian emissions. Due to the characteristics of the Arctic atmosphere, ozone's warming effect in the region appears to be less significant than elsewhere in the world. There remains, however, much uncertainty about modelling ozone formation and fate in the atmosphere, which hampers firm conclusions about the relative roles of different emission sources and source regions on Arctic ozone levels and their resulting effects.

What can be done about SLCPs?

Technological advances and regulatory changes have led to declines in emissions of black carbon and ozone precursors in Arctic countries since 2000. **The technology exists to further reduce SLCP emissions, some of which would reduce emissions of other pollutants, including carbon dioxide, as well.** Projections of future emissions compare scenarios based on current legislation with those based on maximum technically feasible reductions, without regard to cost. What actually happens will depend on the policies that are adopted, which in turn will depend on factors such as cost.

Implementation of maximum technically feasible emission reductions globally for all three SLCPs could reduce projected Arctic warming by up to half a degree C by 2050. **Actions by the Arctic States could make a large contribution to this effort.**

The Arctic warming effects of SLCPs do not require the substances to be in the Arctic themselves. SLCPs warm the entire globe, an impact that is amplified in the Arctic. For this reason, effective action to reduce the Arctic effects of SLCPs cannot be limited to Arctic regions or even Arctic States. Arctic warming is mainly due to rising global temperatures, and must be addressed globally. **Arctic States need to engage the rest of the world in a shared effort to reduce climate forcers of all kinds**.

Methane

Almost half of anthropogenic methane emissions worldwide could be eliminated by 2030 through implementation of existing emission mitigation technologies. Arctic States by themselves have the technical potential to achieve one quarter of global methane emission reductions. It is important to note that maximum technically feasible emission reductions do not take into consideration the economic costs of implementation. These emission reductions can be achieved by:

- changes in venting and flaring practices at oil and gas fields,
- reducing leakage during natural gas production, transportation, and distribution,
- separating and treating or re-using biodegradable waste instead of dumping it in landfills, where its decomposition emits methane, and
- improving coal mining practices to remove or capture rather than release methane.

Agricultural sources of methane are much more dispersed, though emission reductions are possible in this sector, too.

Implementing maximum technologically feasible methane mitigation globally could reduce warming in the Arctic by a few tenths of a degree, and reduce global warming by about a fifth of a degree C by 2050. Action by the Arctic States would make incremental progress towards this result: Arctic States as a single geographic region have the largest technical abatement potential of any major world region for reducing emissions. If global emissions of greenhouse gases continue to increase, resulting in further Arctic warming, additional releases of methane from natural systems in the Arctic are possible, leading to even more rapid warming.

Black Carbon

Reducing black carbon emissions may be possible even more quickly than reducing methane emissions: up to three-quarters of global anthropogenic emissions could be eliminated by 2030. Current regulations on diesel engines and vehicles as well as fuels regulations in a number of jurisdictions have been effective in reducing black carbon emissions from transportation sources. Large gains are still possible by:

- reducing emissions from residential and commercial use of fossil fuels, especially diesel fuel,
- reducing emissions from wood-burning in residential heating, agricultural burning, and wildfires, and
- changing flaring practices at oil and gas fields, especially in Russia.

Although black carbon emissions from Nordic countries are relatively small, they occur in or close to the Arctic, and thus have a larger impact on Arctic warming than similar emissions elsewhere in the world. These reductions would help to reduce warming, although it remains difficult to quantify how much warming could be avoided or to separate the effects of black carbon reductions from those of its co-emitted compounds. In part, this is due to the compounds that are typically emitted with black carbon and that have various effects on climate, including cooling effects. It is also due to the different effects that black carbon itself can have in different seasons and at different altitudes in the atmosphere. **It is estimated that maximum technologically feasible mitigation of black carbon and ozone precursors applied globally could reduce Arctic warming by 2050 with about a quarter of a degree C. This estimate does not include indirect effects of co-emitted OC that could reduce the effect.**

Ozone

Ozone appears to be responsible for relatively little Arctic warming to date. **Action to reduce the emission of ozone precursors would achieve relatively little in the way of direct climate benefits in the Arctic.** Because ozone is formed by pollutants associated with methane and black carbon emissions, action to reduce those substances would also help reduce ozone levels in Arctic air. The estimate of the climate effects of reducing methane emissions given above has taken into account the reduced production of ozone that would result from lower methane levels in the atmosphere.

Key Findings of the 2014 AMAP assessments of SLCPs (black carbon, methane, and ozone)

Arctic warming is part of global warming; consequently, reducing overall global warming will also result in reduced Arctic warming and slow the rate of melting of snow and ice. The role of SLCPs is of particular interest in the Arctic due to the potential for mitigation actions and the fact that the Arctic is warming at about twice the global average due to Arctic amplification.

The most recent assessments of SLCPs (methane, black carbon, and ozone) conducted by AMAP provide new insights into which emission sources and regions contribute most to Arctic climate change, and improved evaluations of how global and regional reductions in these SLCPs may influence projected Arctic warming.

The key findings presented in the two SLCP assessment reports:

1. **Reaffirm that carbon dioxide emissions are the major driver of anthropogenic climate change.** Reductions in carbon dioxide emissions are therefore necessary and urgent if the threats posed by climate change are to be addressed.

2. **Show that mitigation of short-lived climate pollutants, actions that complement carbon dioxide reductions, could slow expected global warming in the period to 2050 by a approximately 0.2 degrees C as a result of maximum technologically feasible actions to reduce methane emissions, and additionally in the Arctic by about 0.25 degrees C degree due to comparable actions to reduce emissions of black carbon and co-emitted air pollutants.** This assumes actions are implemented globally. Uncertainties associated with climate warming and effects of mitigation actions exist for these SLCPs, and are greater for black carbon than for methane.

   While the two assessments that were conducted did not take identical approaches to their evaluations of reduced warming, their results were judged to be sufficiently similar to conclude that, in total, global mitigation of SLCPs could reduce Arctic warming by roughly half a degree C by 2050. These estimates of avoided warming can be compared with an expected Arctic warming due to all climate forcers of approximately 2 degrees C from current levels by 2050.

   Much of the avoided warming from black carbon is associated with reducing black carbon on snow. Indirect (cloud) effects of co-emitted pollutants are not taken into account in the estimate of avoided warming; reduced emissions of these pollutants would offset some of the climate benefits of reduced black carbon emissions. The uncertainties associated with black carbon are largely related to these indirect effects.

3. **Indicate that Arctic states are responsible for about 30% of Arctic warming due to black carbon; the equivalent figure for Arctic warming due to**

methane was not estimated reflecting the fact that location of methane emissions is not a major factor in methane's effects in the Arctic. The following points should be taken into account when considering actions to mitigate SLCPs emissions:

- For methane, Arctic States are responsible for 20% of anthropogenic emissions and have the largest technical abatement potential of any major world region for reducing emissions.
- For black carbon, Arctic states are responsible for about 10% of anthropogenic emissions; mitigation of black carbon emissions in Arctic countries has (per tonne of emitted black carbon) a relatively higher efficacy in reducing Arctic warming;
- Arctic countries are responsible for substantial amounts of SLCP and co-emitted air pollutants from sources associated with important anthropogenic emissions sectors including:
    - for black carbon: small-scale domestic burning (household heating/cooking); transport; and oil and gas activities (flaring) and,
    - for methane: oil and gas activities (venting/leakage); agricultural releases; and solid waste.

4. **Note that since a significant share of Arctic warming is a result of SLCPs emitted outside of the Arctic countries; fully effective mitigation efforts require engagement of non-Arctic countries**.

5. **Identify the need to continue to improve the scientific basis for Arctic Council work on SLCPs and address uncertainties**, in particular with respect to the influence of SLCPs on Arctic warming and effects of SLCP mitigation through future work that should:

- Improve the spatial, temporal, and sectoral resolution of anthropogenic emissions
- Include increased monitoring, research, and modelling.
- Consider SLCP mitigation options in an integrated manner that takes into account SLCPs, greenhouse gases, and co-emitted air pollutants
- Include in this integrated work the assessment of the cost-effectiveness of measures to reduce SLCPs and co-emitted air pollutants.
- Address the co-benefits to human and ecosystem health from actions on carbon dioxide, SLCPs, and other air pollutants.

Glossary*

Black carbon
Soot produced from coal burning, diesel engines, cooking fires, wildfires, and other combustion sources. These particles absorb solar energy and have a warming influence on the climate. This effect is particularly strong on snow and ice, which otherwise reflect most solar radiation (i.e., black carbon reduces surface albedo).

Black carbon: co-emitted pollutants
The processes that release black carbon also release a variety of other pollutants, including short-lived climate forcers (see below for distinction between SLCFs and SLCPs). These pollutants include other fine particulates, sulphur dioxide, various nitrous oxides, and various organic carbon compounds. Some of these other pollutants have cooling effects in the atmosphere.

Global warming
The observed increase in average temperature near the Earth’s surface and in the lowest layer of the atmosphere. In common usage, “global warming” often refers to the warming that has occurred as a result of increased emissions of greenhouse gases and particulates from human activities. Global warming is a type of climate change; it can also lead to other changes in climate conditions, such as changes in precipitation patterns.

Greenhouse gases
Gases that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the greenhouse effect. Greenhouse gases include, for example, carbon dioxide, water vapor, and methane.

Methane
A colorless gas consisting of one carbon atom and four hydrogen atoms. Methane is the main component of natural gas, and is a greenhouse gas.

Mitigation
Measures to reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases and particles or removing carbon dioxide from the atmosphere.

Ozone
A colorless gas consisting of three atoms of oxygen, readily reacting with many other substances. Ozone in the upper atmosphere (stratosphere) protects the Earth from harmful levels of ultraviolet radiation from the Sun. In the lower atmosphere (troposphere) ozone is an air pollutant with harmful effects on human health. Ozone is also a greenhouse gas.

Ozone precursors
Substances that are part of chemical reactions in the atmosphere that create ozone. These include nitrogen oxides, volatile organic compounds, methane, and carbon monoxide. Ozone is thus largely a secondary pollutant, its levels depending on the emissions of its precursors.

Short-lived climate forcers (SLCFs)
Gases and particles that have atmospheric lifetimes from a few days to a decade and warming or cooling effects on climate. SLCPs (see next entry) are those SLCFs that produce warming. The IPCC uses the term “near-term climate forcers” (NTCFs) for the same group of gases and particles.

Short-lived climate pollutants (SLCPs)
Gases and particles that have atmospheric lifetimes ranging from a few days to a decade and that exert a warming influence on climate. The main short lived climate pollutants are black carbon, methane and tropospheric ozone, which are the most important contributors to the human enhancement of the global greenhouse effect after carbon dioxide. Some short-lived climate pollutants are also dangerous air pollutants, with various detrimental impacts on public health, agriculture, and ecosystems.

*Adapted from the U.S. Global Change Research Program, the Climate and Clean Air Coalition, and other sources