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CO-CONTROL OF AIR POLLUTION AND SURFACE AIR TEMPERATURE

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SUMMARY

The IPCC Special Report: Global Warming of 1.5°C (IPCC, 2018) found that it is difficult to reach the 1.5°C target of the Paris Agreement by only reducing long-lived carbon dioxide (CO_2) emissions. There is growing international awareness of the potential to mitigate climate change by reducing emissions of short-lived climate forcers (SLCFs), many of which come from same CO_2 emission sources. SLCFs include tropospheric ozone (O_3) and its precursors, methane, hydrofluorocarbons, and suspended particulate matter (i.e., aerosols) and their precursors. This policy brief describes the basic scientific knowledge needed to develop air pollution reduction policies in the context of climate change mitigation.

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SLCF gases with infrared absorption properties warm the atmosphere through a mechanism similar to that of CO_2. SLCF aerosols mainly scatter and absorb sunlight, contributes to climate change through a different mechanism than that caused by greenhouse gases.

One of the key message in this policy brief is that **reduction in majority of aerosol species may accelerate global warming, although emission reduction of SLCFs will bring direct and immediate benefits for health. It is important to develop reduction pathways considering aerosol species**, rather than treating $PM_{2.5}$ as a whole.

Another important message is that estimates of temperature change due to SLCFs had been based solely on radiative forcing, which is the change in the energy balance. Recent studies have shown that the surface air temperature change per aerosol radiative forcing (i.e. a climate sensitivity parameter) much depends on aerosol components. **Since climate change research on SLCFs is a rapidly progressing field, policymaking needs to be based on the latest quantitative evaluation, considering net impacts of all components**.

INTRODUCTION

Climate change, like many other physical phenomena, is primarily caused by an imbalance in the energy budget. The Earth's surface sphere (atmosphere, oceans, and land) receives energy from the sun and emits the same amount of received energy as infrared radiation to maintain the equilibrium. As the concentration of greenhouse gases (GHGs) continues to increase due to human activities and the absorption of infrared radiation increases, it is clear that the energy equilibrium has been disrupted. As a result, heat energy stored in oceans and land surface are being transported to the atmosphere, causing temperatures to rise.

It is estimated that the current stated mitigation ambition in Nationally Determined Contributions (NDCs) will still lead to an increase in global mean surface air temperature of about 3°C in this century relative to the preindustrial levels (IPCC 2018), which would clearly miss the Paris Agreement target. At this rate, the loss of life and economy caused by flooding associated with heavy rainfall, heat waves, and other weather-related disasters will only worsen. **Reducing emissions of short-lived climate forcers (SLCFs), most of which are air pollutants, could provide additional means for mitigating global warming in the next several decades.**

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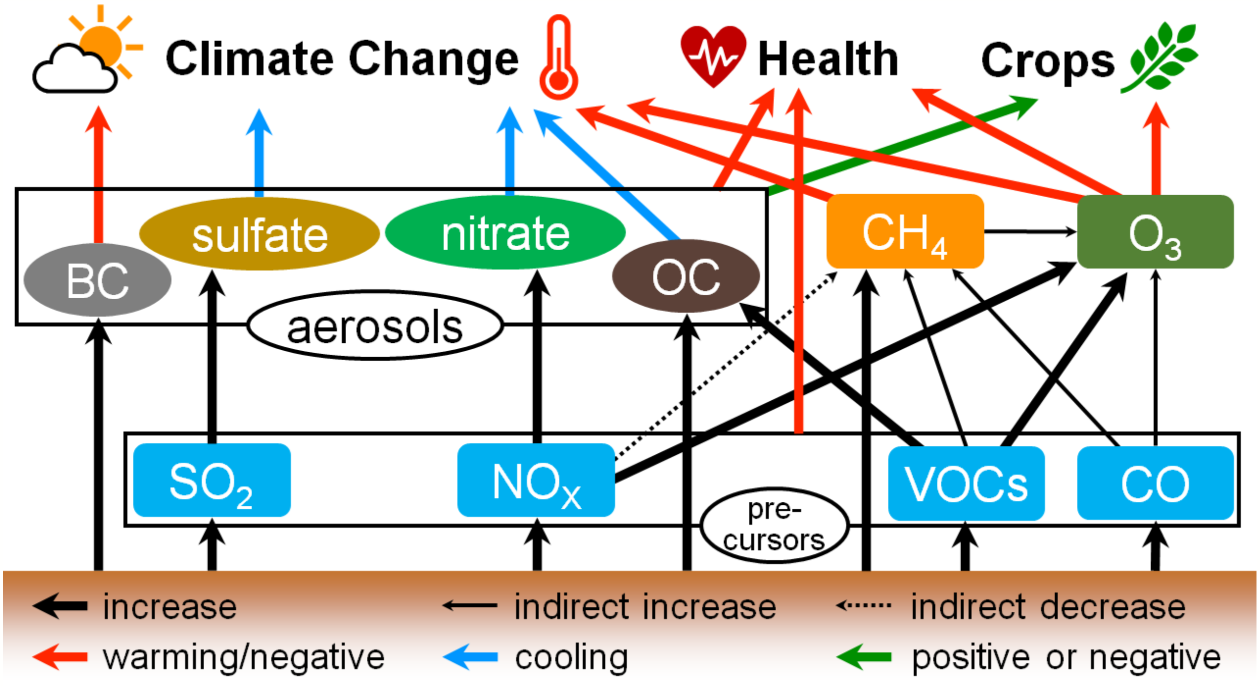
MECHANISM OF CLIMATE CHANGE BY SLCFS

The main SLCFs are tropospheric ozone (O_3) and its precursors, methane (CH_4), hydrofluorocarbons (HFCs), and suspended particulate matter (i.e., aerosols including sulfate, nitrate, organic matter, and black carbon) and its precursors. Smaller aerosol particles less than 2.5 μm in diameter is $PM_{2.5}$. Their main characteristics and mechanisms of climate change are described in this section. The definition of short-lived climate pollutants (SLCPs) by the Climate and Clean Air Coalition (CCAC) is a subset of SLCFs which absorb solar and infrared radiation and then stores energy in the Earth's surface and atmosphere, i.e., CH_4, tropospheric O_3, HFCs, and black carbon (BC).

As shown in Figure 1, SCLFs have a complicated relationship with each other, so **it is necessary to carefully consider and decide the pathway for optimizing the impact mitigation by SLCFs as a whole**. Since O_3, CH_4, and HFCs are gases that absorb infrared radiation, the mechanism of climate change caused by them is the same as that of CO_2.

Figure 1: Relationship among SLCFs and their precursors and effects of SCLFs on climate change, health, and crops. Note that this figure shows the effect of increasing SLCFs and their precursors, and therefore the effect is reversed when they are reduced.



1. Tropospheric ozone (O_3)

Tropospheric or ground level ozone is a major component of photochemical oxidants. It is not directly emitted, but is produced by chemical reactions of nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. Increases in CH_4 and carbon monoxide (CO) also contribute to the formation of O_3. It has direct negative impacts on health and crops.

2. Methane (CH_4)

Increase in CH_4 is due to direct emissions from anthropogenic sources from agriculture, coal mining, oil and gas production and distribution, biomass burning, and municipal waste landfilling. It is also due to reduction of hydroxyl (OH) radicals due to the presence of CO and VOCs, because CH_4 is eliminated by OH radicals. On the other hand, CH_4 decreases with an increase in NOx because OH radicals are generated in the chemical reaction that produces tropospheric O_3 from NOx.

3. Hydrofluorocarbons (HFCs)

HFCs are used as a major refrigerant and their atmospheric concentrations continue to rise. The CCAC aims to reduce HFCs emissions under the Efficient Cooling Initiative initiated in 2019.

4. Aerosols

Aerosols are a general term for fine particles with a radius of approximately 1 nm to 100 μm. Most aerosols originating from human activities are classified as $PM_{2.5}$, a smaller category of aerosols. The largest source of anthropogenic aerosols is the combustion of fossil fuels, which produces sulfur dioxide (SO_2) (a precursor of sulfate aerosol), NOx (a precursor of nitrate aerosol and O_3), organic aerosols, and black carbon (BC). Most of these are also produced by biofuel consumption and forest fires.

The mechanism of aerosols’ effects on the climate system can be generally divided into two categories. First, because of aerosols’ light scattering and absorbing properties, their energy balance is disrupted when aerosol concentrations change. This is called “aerosol-radiation interaction”. Sulfate, nitrate, and organic aerosols, which are transparent or white aerosols, cool the atmosphere because they scatter sunlight back into space, while black carbon heats the atmosphere because it absorbs sunlight more than scattering.

The aerosol-radiation interaction is visually recognizable as a phenomenon that causes the atmosphere to appear hazy at high concentrations of $PM_{2.5}$.

Another mechanism is the change in cloud properties as aerosol particles become cloud condensation nuclei for water cloud or ice nuclei for ice cloud. This is known as “aerosol-cloud interaction”. Clouds effectively scatter sunlight to create shade and absorb infrared radiation to prevent radiative cooling at night. In other words, a change in clouds is a significant factor in climate change because they cause a change in the energy balance.

Anthropogenic aerosols also have a direct negative impact on human health. In addition, while crop yields may be reduced as temperature decreases due to aerosol-radiation and aerosol-cloud interactions, yield may increase due to enhanced photosynthesis with increased scattered sunlight by the aerosol-radiation interaction.

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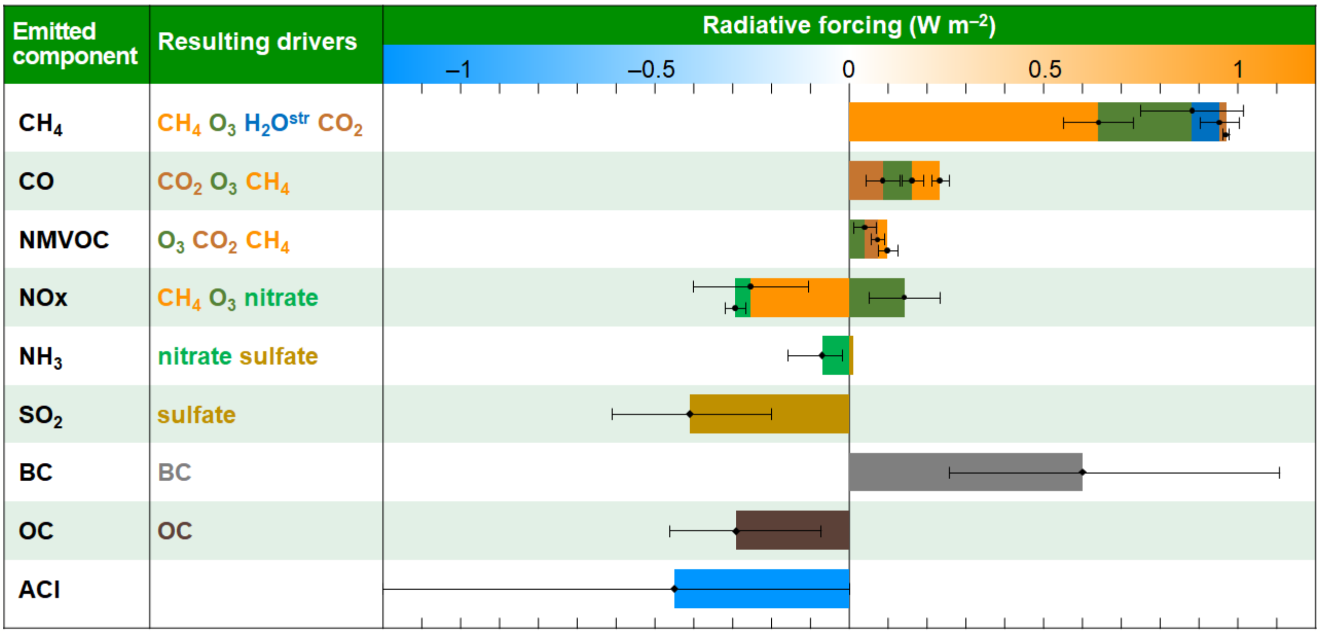
CO-CONTROL OF AIR POLLUTION AND SURFACE AIR TEMPERATURE CHANGE

Figure 2 shows the annual and global mean values of the energy imbalance “radiative forcing” due to anthropogenic SLCFs as of 2011 by emitted components. Considering the estimated radiative forcing due to CO_2 of +1.68 W m^{-2}, it is clear that the overall impact of the SLCFs must be considered. Although the positive radiative forcing from CH_4 emissions is significant, alternative emission reduction measures are needed because methane is largely derived from sources other than fossil fuels.

Figure 2 indicates that, **if emission reductions related to SOx and NOx, which are mostly emitted from fossil fuel combustion, are implemented by end of pipe measures only without accompanying CO_2 emission reduction measures, global warming will be accelerated. This indicates that emission reduction of long-lived GHGs and SLCFs must be implemented simultaneously.** While there are still limited studies on short-term and long-term costs of climate change adaptation and mitigation measures on society, the combined implementation of SLCFs measures with long-lived GHGs could lead to cost savings for society as a whole in the long term.

Figure 2: Global and annual mean radiative forcing due to anthropogenic SLCFs as of 2011 partitioned according to the emitted components assessed by IPCC (2013). Resulting drivers shown by color mean the components in the atmosphere after chemical reaction.



* H_2O^{str}: water vapor at stratorphsre; NMVOC: non-methane VOC; ACI: aerosol-cloud interaction

It has been common practice to estimate temperature changes from the values of radiative forcing. For example, the surface air temperature change per radiative forcing (i.e., a climate sensitivity parameter) was assumed to be the same as that of CO_2 when estimating the effect of reducing CH_4 and BC on mitigating global warming (Figure 6.1 in UNEP and WMO 2011). However, recent studies with detailed analysis using coupled atmosphere-ocean climate models have found that the climate sensitivity parameter for BC is very small (Samset et al. 2016; Stjern et al. 2017; Takemura and Suzuki 2019). This is because, unlike GHGs, there is a mechanism to counteract the positive radiative forcing created by BC due to absorbing sunlight (Suzuki and Takemura 2019).

CONCLUSION

Since fossil fuel consumption is a primary common anthropogenic source of CO_2 and most SLCFs, a comprehensive understanding of climate change caused by both is essential. Measures to reduce SLCFs for climate benefits should be based on the latest quantitative assessments which considers multiple impacts such as climate extremes (e.g., heat wave and heavy rain), floods, health, and crop yields. For example, in Japan, a recent integrated study was conducted to assess SLCFs impacts and to identify the optimal reduction pathway for SLCFs emissions (Nakajima et al. 2020), and more detailed studies are planned.

The IPCC Task Force on National Greenhouse Gas Inventories (TFI) has started process to develop new guidelines for estimating emissions of SLCFs. This means that countries may be required to report SLCFs emissions in the near future in addition to Kyoto-GHGs. **Optimal air pollutant reductions are becoming increasingly important in the context of climate change mitigation as simultaneous mitigation of SLCFs and long-lived GHGs is needed to help us achieve the Paris Agreement's targets.**

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