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Climate Benefits from Methane Mitigation †

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Abstract: Methane is a greenhouse gas with a lifespan of about a decade, and its presence in the atmosphere affects the Earth's temperature and the climate system. Methane is included in short-lived climate forcers (SLCFs) or near-term climate forcers (NTCFs), whose atmospheric composition changes have a near-term effect on climate, predominantly in the first two decades after their emission or formation. In this study, the climate benefits of methane mitigation on global air temperature distribution are examined for the near future (2031–2050). The analysis is based on model simulations conducted by the Earth System Model GFDL-ESM4 for the future scenario SSP3-7.0 with additional air quality mitigation measures either in non-methane NTCFs (aerosol and ozone precursors) or in all NTCFs (including methane). It is shown that additional methane mitigation would potentially further contribute to offsetting the warming from reduced aerosols associated mainly with SO_2 reductions that would accompany decarbonization.

Keywords: methane; methane mitigation; temperature; climate benefits; emission scenarios; SSPs; short-lived climate forcers

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1. Introduction

Methane, as a well-mixed greenhouse gas with a lifetime of about a decade, is emitted by a variety of human-influenced and natural sources. Methane is a direct short-lived climate forcer (SLFC) or a near-term climate forcer (NTCF) since it affects the climate through radiative forcing (RF) [1]. Methane's presence affects the abundance of other greenhouse gases, and its emissions-based effective radiative forcing (ERF) is roughly 60% of the emissions-based ERF caused by carbon dioxide [2]. Also, methane has a Global Warming Potential (GWP) about 27–30 times larger than carbon dioxide [3]. As such, a potential significant mitigation of methane would result in an intense and significant effect on atmospheric warming potential [4]. However, methane's atmospheric concentration over the last centuries has more than doubled, primarily due to human-related activities. As current measurements have shown that methane concentrations will continue to increase, the importance of methane mitigation has emerged. Methane and some halogenated compounds are included in climate treaties, unlike the other SLCFs, that are nevertheless indirectly affected by climate change mitigation since many of them are often co-emitted with CO_2 in combustion processes [2]. According to Allen et al. [1], a reduction in methane emissions will simultaneously mitigate climate change and air pollution by offsetting the warming caused from the reduction in scattering aerosols and by improving air quality. In this study, the benefits of methane mitigation on climate are examined, focusing on the effect of methane mitigation on air temperature distribution over different latitudes and atmospheric pressure levels.

2. Methods

The analysis is based on model simulations conducted by the Earth System Model GFDL-ESM4 [5] for the future shared socioeconomic pathway scenario SSP3-7.0 with additional air quality mitigation measures either in non-methane NTCFs (aerosol and ozone precursors; NMNTCF) or in all NTCFs (including methane) as part of the Aerosol and Chemistry Model Intercomparison Project (AerChemMIP) [6]. AerChemMIP commonly uses SSP3-7.0 ($\sim$7.0 W m^{-2} at 2100) as a reference scenario to detect the impact of air quality pollutants, because it lacks climate policy, and it has 'weak' levels of air quality control measures [1], thus resulting in the highest levels of NTCFs [7,8].

Hence, the SSP3-7.0 serves as the reference experiment in the simulations. The second scenario is the SSP3-7.0-lowNTCF, which excludes methane changes and in this study is considered to be a strong non-methane air quality control experiment. Additionally, the SSP3-7.0-lowNTCF scenario provides the opportunity to quantify the climate and the air quality benefits due to NMNTCF mitigation policies [1]. The third scenario is the SSP3-7.0-lowNTCFCH$_4$, which includes methane and NMNTCFs and is considered to be a strong air quality control experiment. The SSP3-7.0-lowNTCFCH$_4$ scenario allows the quantification of all NTCFs mitigation policies (including methane) [1].

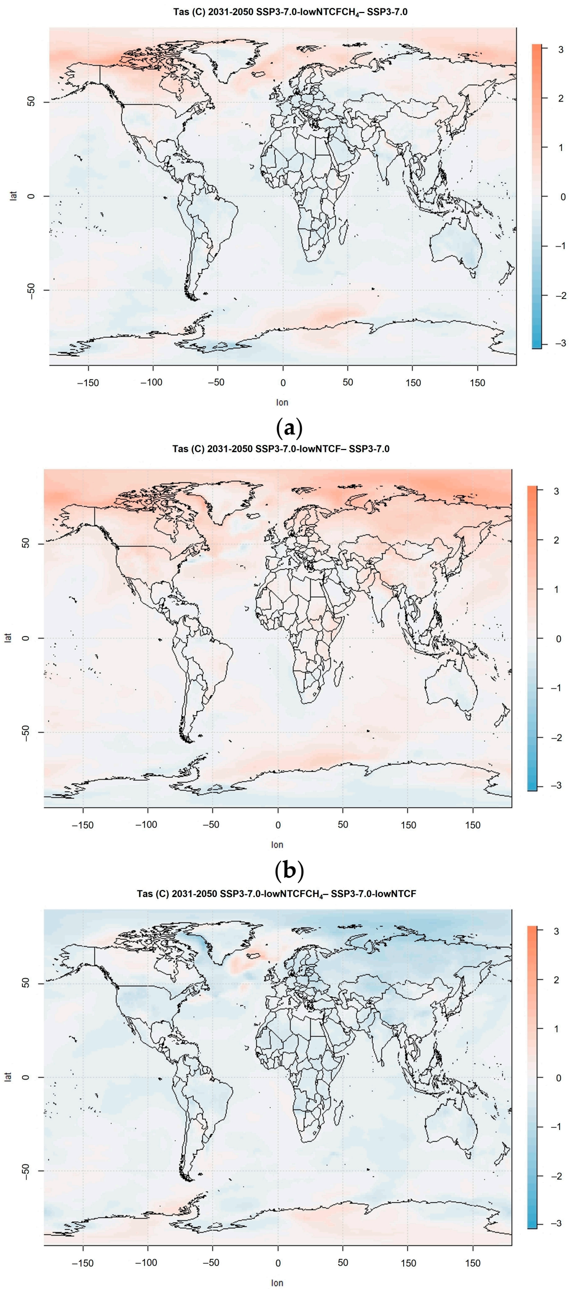
Focusing on the importance of methane mitigation, three cases of mitigation policies are presented here, one for NTCF mitigation, one for NMNTCF mitigation and one for methane mitigation. More specifically, NTCF mitigation is defined as the difference between the strong air quality control experiment which includes methane (SSP3-7.0-lowNTCFCH$_4$), and the corresponding weak air quality control experiment (SSP3-7.0). Similarly, NMNTCF mitigation is defined as the difference between the strong air quality control experiment which excludes methane (SSP3-7.0-lowNTCF) and the reference scenario with weak air quality control measures (SSP3-7.0). The effect of methane mitigation is defined as the difference between the strong air quality experiments SSP3-7.0-lowNTCFCH$_4$ and SSP3-7.0-lowNTCF, which include and exclude methane, respectively [1].

One future period has been selected for the evaluation of methane mitigation policies focusing on the near future (2031–2050). For this period, the influence of NTCF, NMNTCF and methane mitigation policies over time was analyzed by comparing the projected near surface air temperature and the latitude–pressure air temperature distribution by each mitigation policy.

3. Results

The simulation was run for the near future period of 2031–2050, showing that NTCF mitigation and the methane mitigation policy would cause a decrease in surface temperature, whereas the NMNTCF mitigation policy would cause an increase in surface temperature (Figure 1). Over the Northern Hemisphere, the surface temperature ranged between -1 °C and 2 °C when applying the NTCF mitigation scenario including methane (Figure 1a) and between -3 °C and 1 °C when applying only the methane mitigation scenario (Figure 1c). On the other hand, when applying the NMNTCF mitigation scenario, the surface temperature ranged between -1 °C and 3 °C (Figure 1b). In the same context, over the Southern Hemisphere the NMNTCF mitigation scenario led to higher surface temperatures than the NTCF mitigation and the methane mitigation scenarios. It is also shown that over the Northern Hemisphere the methane mitigation policy led to lower surface temperatures than the NTCF mitigation policies. Over the Southern Hemisphere, the surface temperature was slightly lower when applying the methane mitigation scenario when the NTCF mitigation scenario was applied. Bear in mind, also, that apart from the radiative effects, the cooling/heating patterns are additionally influenced by dynamical effects due to changes in the general circulation of the atmosphere.

Figure 2a shows that NTCF mitigation including methane would result in the cooling of a large part of the troposphere and warming over high latitudes of the Northern Hemisphere for the near future period (2031–2050). On the other hand, the NMNTCF mitigation policy would result in the heating of the largest part of the troposphere (Figure 2b), mainly associated with a reduction in scattering aerosols. It should be noted that the warming over high latitudes of the Northern Hemisphere from NTCF mitigation including methane (Figure 2a) was smaller than the respective warming from NTCF mitigation excluding methane (Figure 2b). Hence, cooling with the inclusion of methane in NTCF mitigation policies would partially counterbalance the warming from reduced aerosols in the near-future period. Bear in mind, also, that apart from the radiative effects, the cooling/heating patterns are additionally influenced by dynamical effects due to changes in the general circulation of the atmosphere. According to Figure 2c, the methane mitigation policy would result in cooling over the largest part of the troposphere. More specifically, in high latitudes of the Northern Hemisphere, the methane mitigation would cause cooling instead of the projected warming when applying the NTCF mitigation.



(**a**) (**b**) (**c**)

Figure 1. Distribution of annual near-surface air temperature difference for the near-future period (2031–2050): (**a**) by NTCF mitigation (SSP3-7.0-lowNTCFCH_4—SSP3-7.0), (**b**) by NMNTCF mitigation (SSP3-7.0-lowNTCF—SSP3-7.0), and (**c**) by methane mitigation (SSP3-7.0-lowNTCFCH_4—SSP3-7.0-lowNTCF).

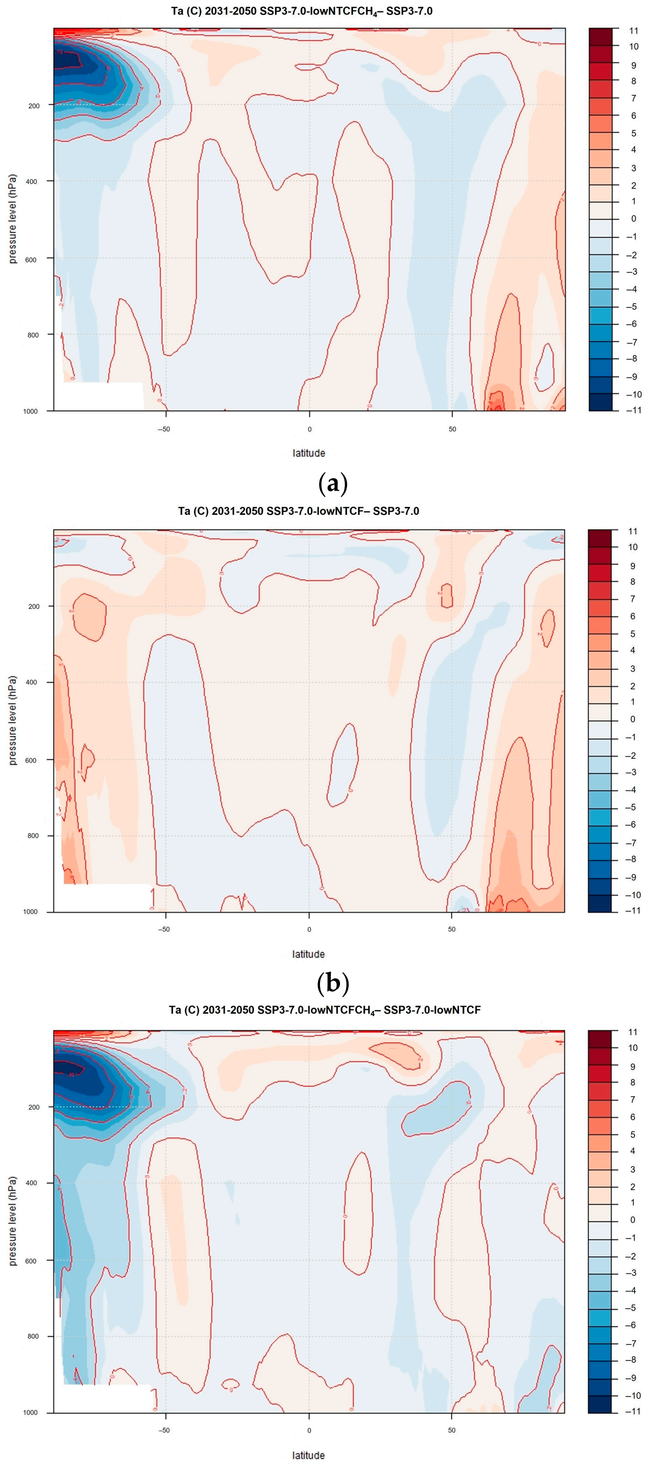


Figure 2. Zonally averaged annual latitude–pressure cross section of air temperature difference as projected for the near future (2031–2050): (**a**) for the NTCF mitigation (SSP3-7.0-lowNTCFCH$_4$—SSP3-7.0), (**b**) for the NMNTCF mitigation (SSP3-7.0-lowNTCF—SSP3-7.0) and (**c**) for the methane mitigation (SSP3-7.0-lowNTCFCH$_4$—SSP3-7.0-lowNTCF).

4. Conclusions

The main purpose of this study is to emphasize the importance of methane mitigation on global air temperature distribution for the near future (2031–2050). The analysis is based on model simulations conducted by the Earth System Model GFDL-ESM4 for the future scenario SSP3-7.0 with additional air quality mitigation measures either in non-methane NTCFs (aerosol and ozone precursors) or in all NTCFs (including methane). The results show that the reduction of non-methane NTCFs will cause the heating of the atmosphere, mainly due to reduced aerosols associated with SO_2 reductions that would accompany decarbonization. When adding methane into the climate mitigation policies, there was a tropospheric cooling effect over time towards the end of the 21st century which would contribute to offset the warming from reduced aerosols in the near-future period.

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