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Supporting Information for

Infrared radiative effects of increasing CO_2 and CH_4 on the atmosphere in Antarctica compared to the Arctic

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Contents of this file

Text S1 to S3

Figures S1 to S7

Introduction

The supporting information contains:

- a description how to calculate ΔT_{res} for the surface
- a Figure showing results for the longwave temperature change, ΔT_{res}, and the resulting temperature change
- A description and Figure showing the accuracy of simulated temperatures versus ERA5 data
- A Figure showing the simulations using 52 trace gases.
- A description and Figure for testing our program using the US Standard atmosphere
- a Figure showing the temperature development up to 90 km;
- a Figure with typical mixing ratios of H_2O for the Arctic and Antarctica;
- a Figure showing the difference in the downwards radiation for CO_2 when doubling CO2 below or above 8 km.

Text S1.

Calculation of the surface temperature and $\Delta T_{res}(z=z_0)$

Since the heat capacity of the surface is unknown, the surface temperature change ΔT_{surf} was calculated using the energy budget

$$\Delta T_{surf} = C_{cal} (\Delta F_{LW} + \Delta F_{SW}) + \Delta T_{res}(z=z_0) \qquad (S1)$$

where ΔF_{LW} and ΔF_{SW} are the long-wave and short-wave net radiative fluxes. $\Delta T_{res}(z=z_0)$ incorporates all remaining surface energy fluxes, namely sensible and latent heat flux as well as any ground heat flux. The calibration parameter C_{cal} was determined from surface radiation and 2 m air temperature measurements by linear regression, averaged for each month. ΔF_{LW} was taken from our atmospheric simulations, ΔF_{SW} was taken from the regression analysis of field measurements. All Antarctic calculations were performed using South Pole BSRN station measurements from 2010 until 2017 (Riihimaki et al., 2023). Arctic simulations were carried out using MOSAiC field measurements (Pirazzini et al., 2022) from 2019 and 2020.

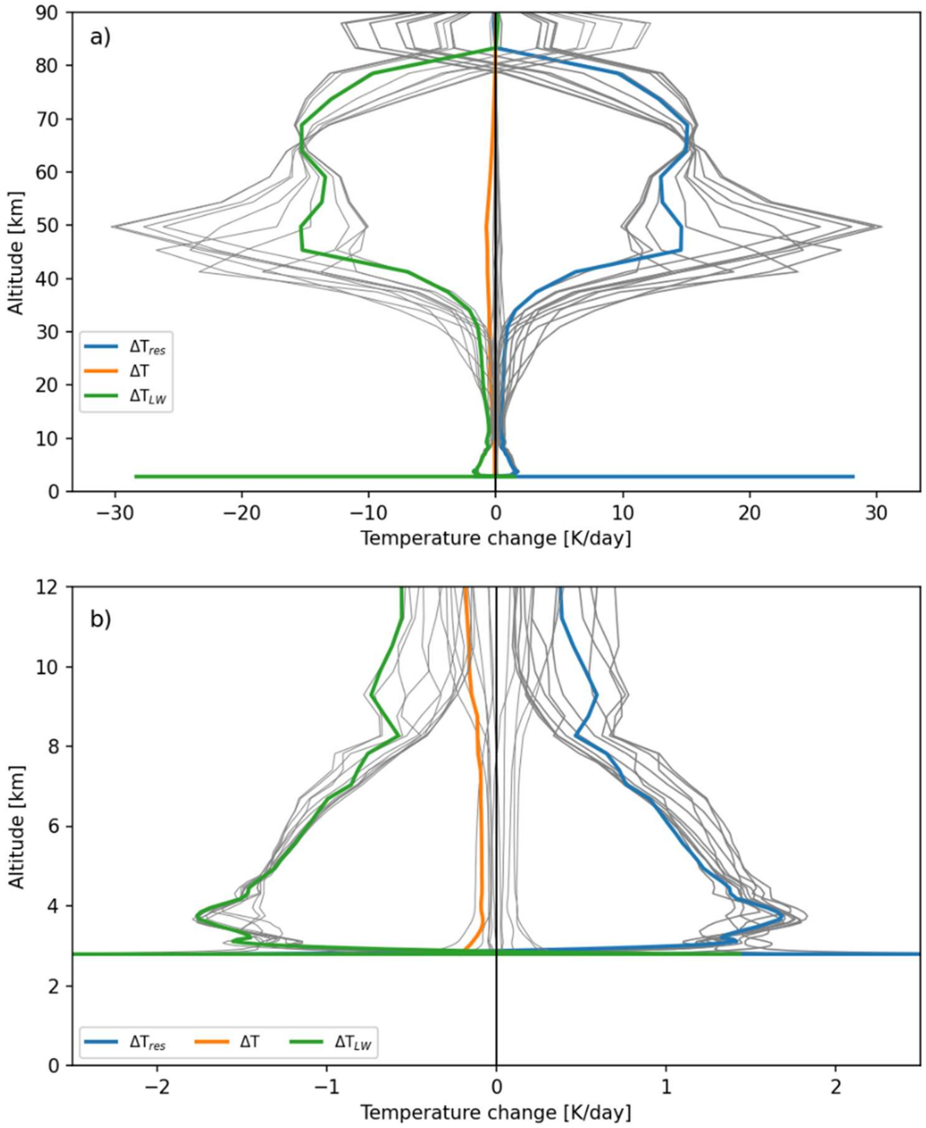

Figure S1: Simulated temperature change in the infrared $\Delta T_{LW}(z, t)$ (green), calculated $\Delta T_{res}(z, t)$ (blue), and resulting total temperature change $\Delta T(z, t)$ (orange) for 15 March in Antarctica, calculated for a time step of three hours. Results for the other months are shown as thin gray lines. (a) up to 90 km, (b) up to 12 km.

Text S2.

Accuracy of ΔTres

Figure S2 shows the difference (monthly running mean) between ERA5 data and the simulated temperature development for a whole year in Antarctica for 5 selected atmospheric layers and the surface layer (2789 m). The maximum differences are within ±0.1 to ±0.2 K. For all other altitudes not shown, the differences are in the same range. The variability is due to the use of monthly averaged ΔTres and the numerical effects of the temporal interpolation. For longer periods of a few months the ERA5-based input and simulated temperatures agree to much less than ±0.05 K. Temperature deviations after three years of simulation are equal to those at the beginning of the third year of the simulation within ±0.01 K, hence the model has reached an equilibrium state.

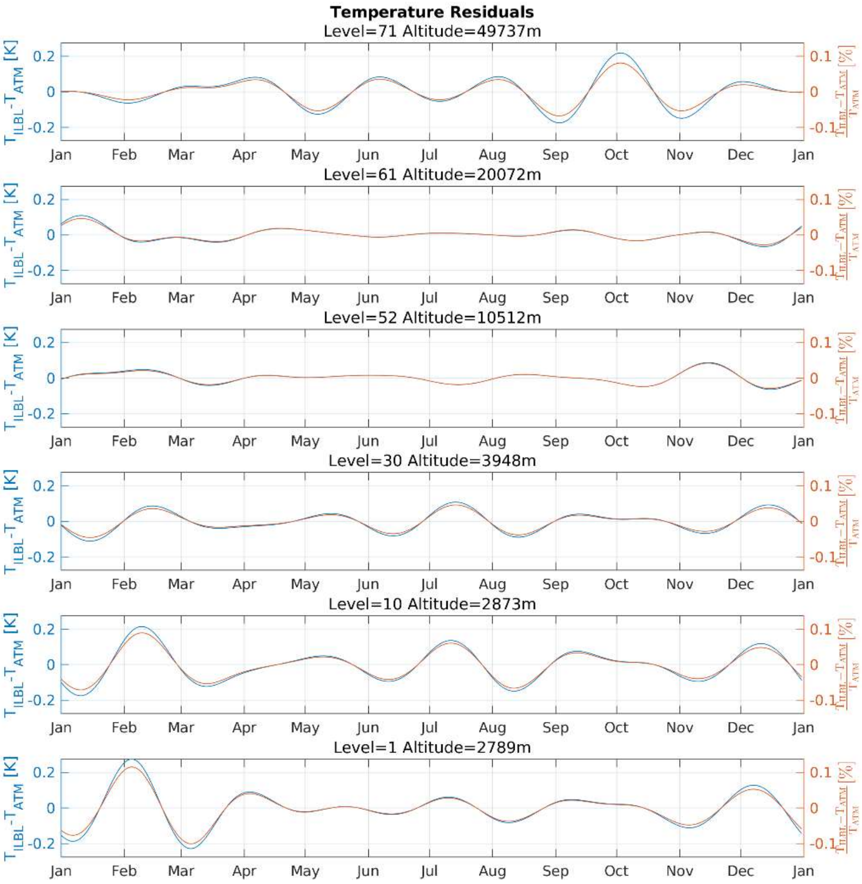

Figure S2: Difference (in K and %) between the Antarctic (South Pole) atmospheric temperatures based on ERA5 climatology (monthly averaged, spline interpolated) and the simulations for five atmospheric layers and the surface (lowest panel, South Pole station is at 2789 m). The simulation was started on 1 January and run for 3 years, the residuals shown here are those of the third year.

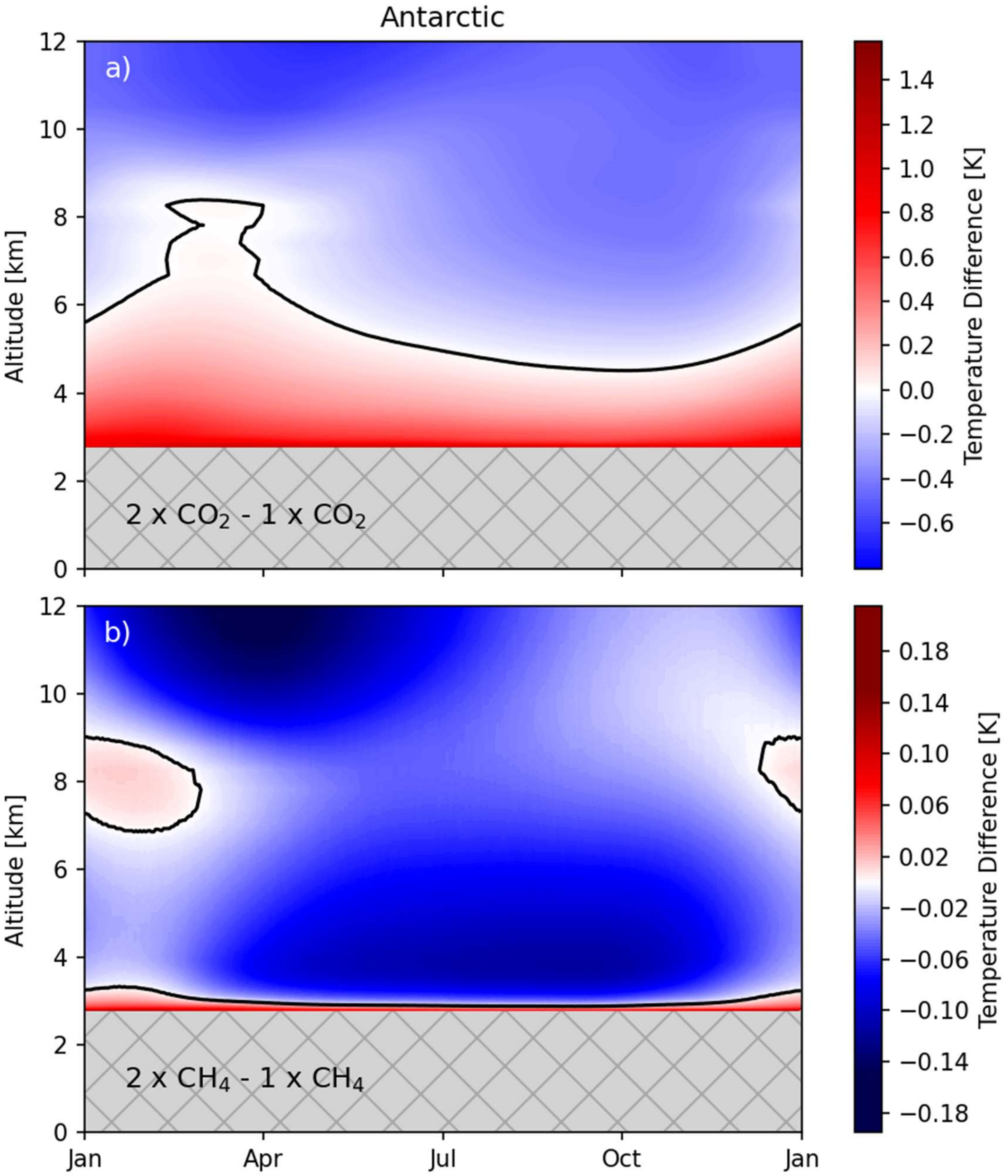

Figure S3: Temperature forcing (K) as a function of altitude throughout the year calculated using 52 trace gases. For $2 \times CO_2 - 1 \times CO_2$ (a) and $2 \times CH_4 - 1 \times CH_4$ (b) for Antarctica. In Antarctica the surface is at 2.8 km altitude, in the Arctic at 1 m.

Text S3.

Test of our program using the US Standard atmosphere

In order to test our code we have applied our program also to the US-Standard atmosphere. Since in the US-Standard calculations no seasonal variability is present, only one $\Delta T_{res}(z, t)$ needs to be calculated, and it was not necessary to interpolate $\Delta T_{res}(z, t)$ for the specific times of simulation. Therefore the difference between the US-Standard profile and the simulations with the prescribed $\Delta T_{res}(z, t)$ for 1xCO_2 remain within ±0.01 K, caused by numerical inaccuracy of the code with its iterative calculations. For 2xCO_2 the calculations have reached an equilibrium after about four months (4000 steps with 0.5 hour time step), which means, the subsequent temperature change was within the accuracy when simulating 1xCO_2 (0.01 K) (Fig. S5). For these runs the water vapour feedback was considered, which means, the relative humidity was kept constant during the temperature evolution. For 2xCO_2 we find a temperature increase of 2.2 K at 2 m altitude. This is in good agreement with studies by Gillett et al. (2013), who utilized a global climate models to quantify the “transient climate response to cumulative carbon emissions” of 1.3 K/EgC (“best estimate”). Taking into account their given preindustrial carbon content of approximately 1 EgC and a present-day cumulative emission of 0.5 EgC these numbers translate to 1.95 K warming for the transition from 400ppm to 800ppm that we are considering here.

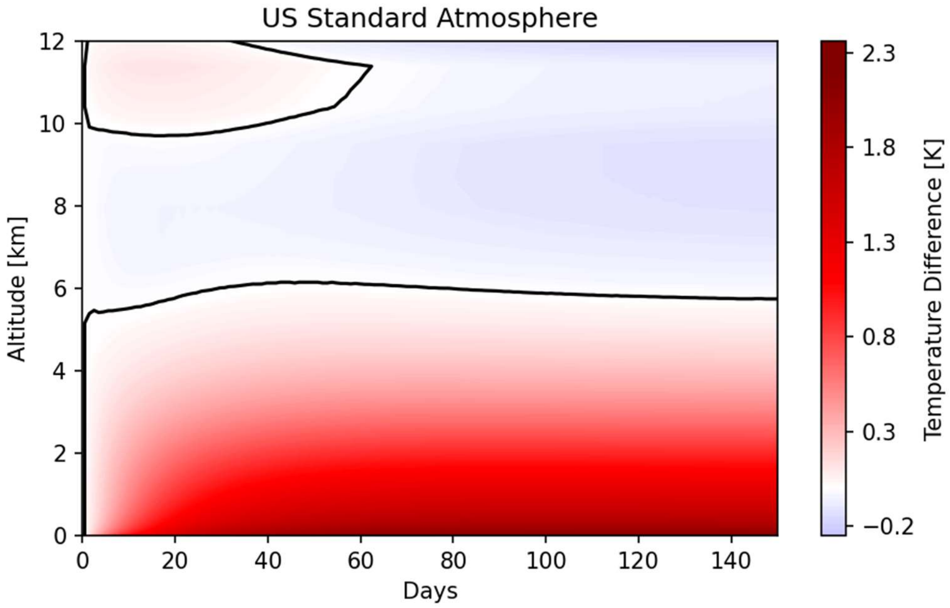

Figure S4: 2 x CO_2 – 1 x CO_2 using the US-standard atmosphere. In the troposphere the new equilibrium is reached after about 140 days with 0.5 hour step size (approx. 4 months).

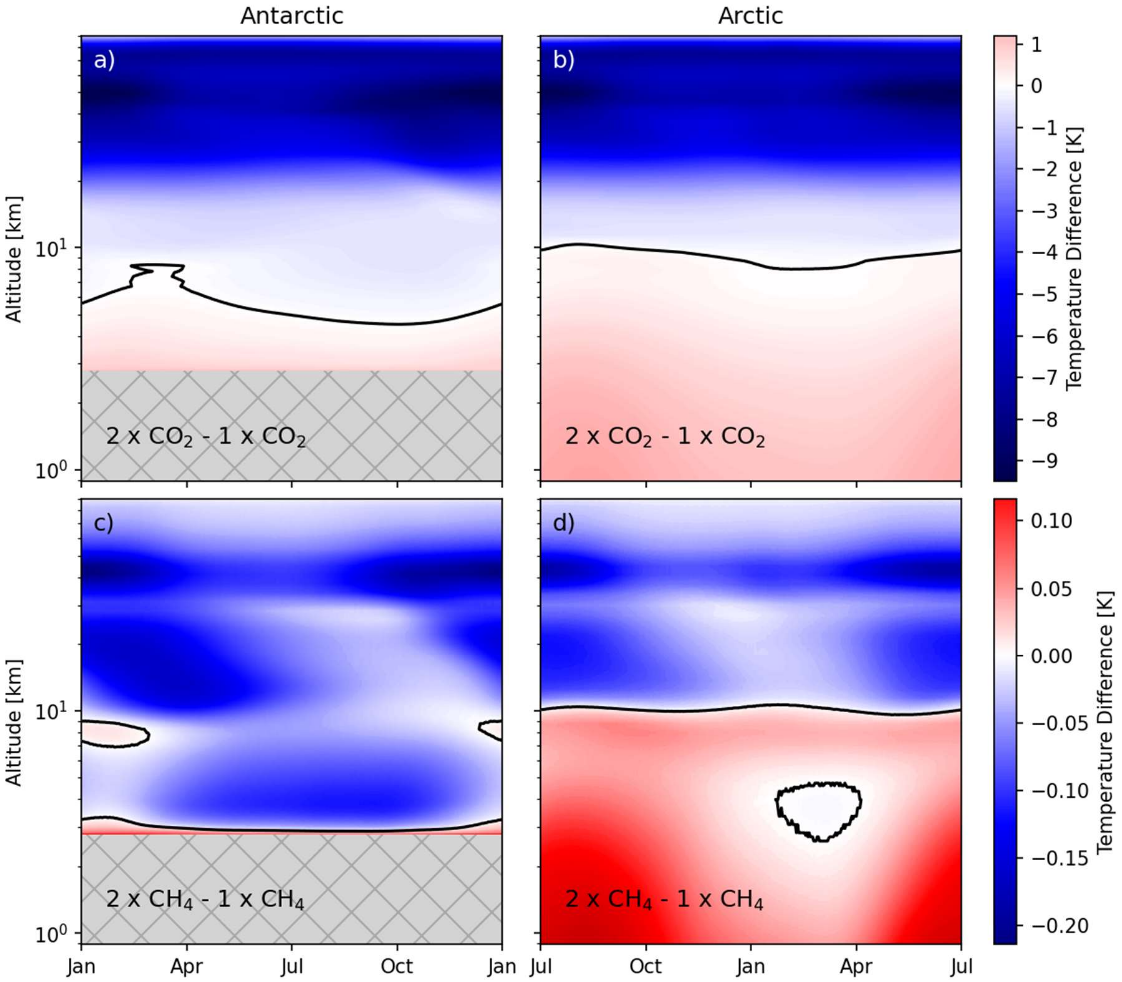

Figure S5. Same as Fig.1, but for the altitude region up to 90 km on a logarithmic scale. ΔT (K) as a function of altitude throughout the year calculated for 2 x CO_2 - 1 x CO_2 (a and b) and 2 x CH_4 - 1 x CH_4 (c and d) for Antarctica (a and c) and the Arctic (b and d). In Antarctica the surface is at 2.8 km altitude, in the Arctic at 1 m.

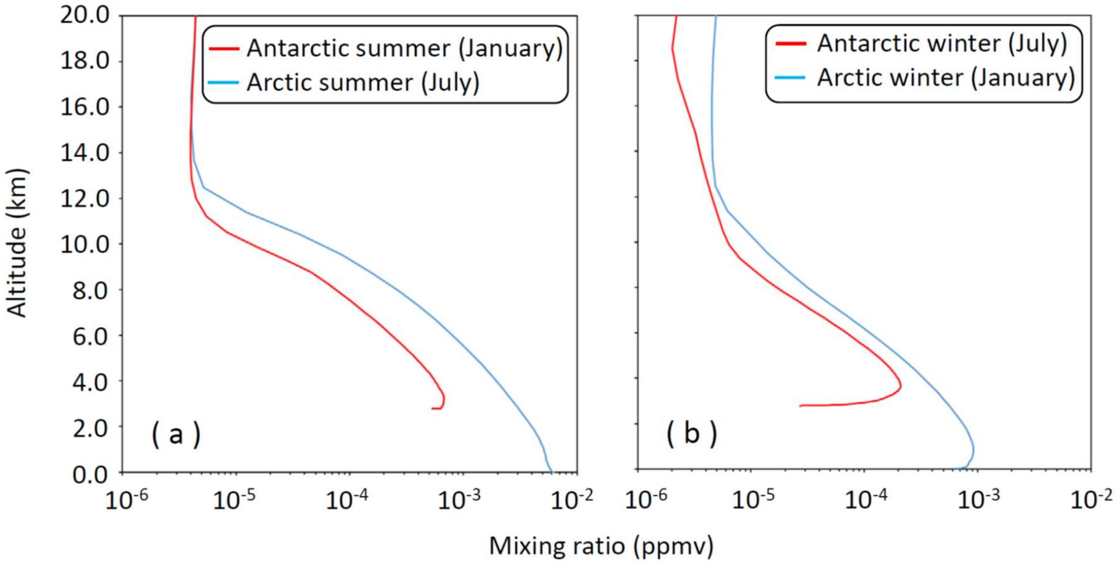

Figure S6. Figure S4: H_2O mixing ratio profiles up to 20 km altitude. Shown are monthly averages based on sondes and ERA-5 data. (a) summer (blue: Arctic; red: Antarctica), (b) winter (blue: Arctic; red: Antarctica).

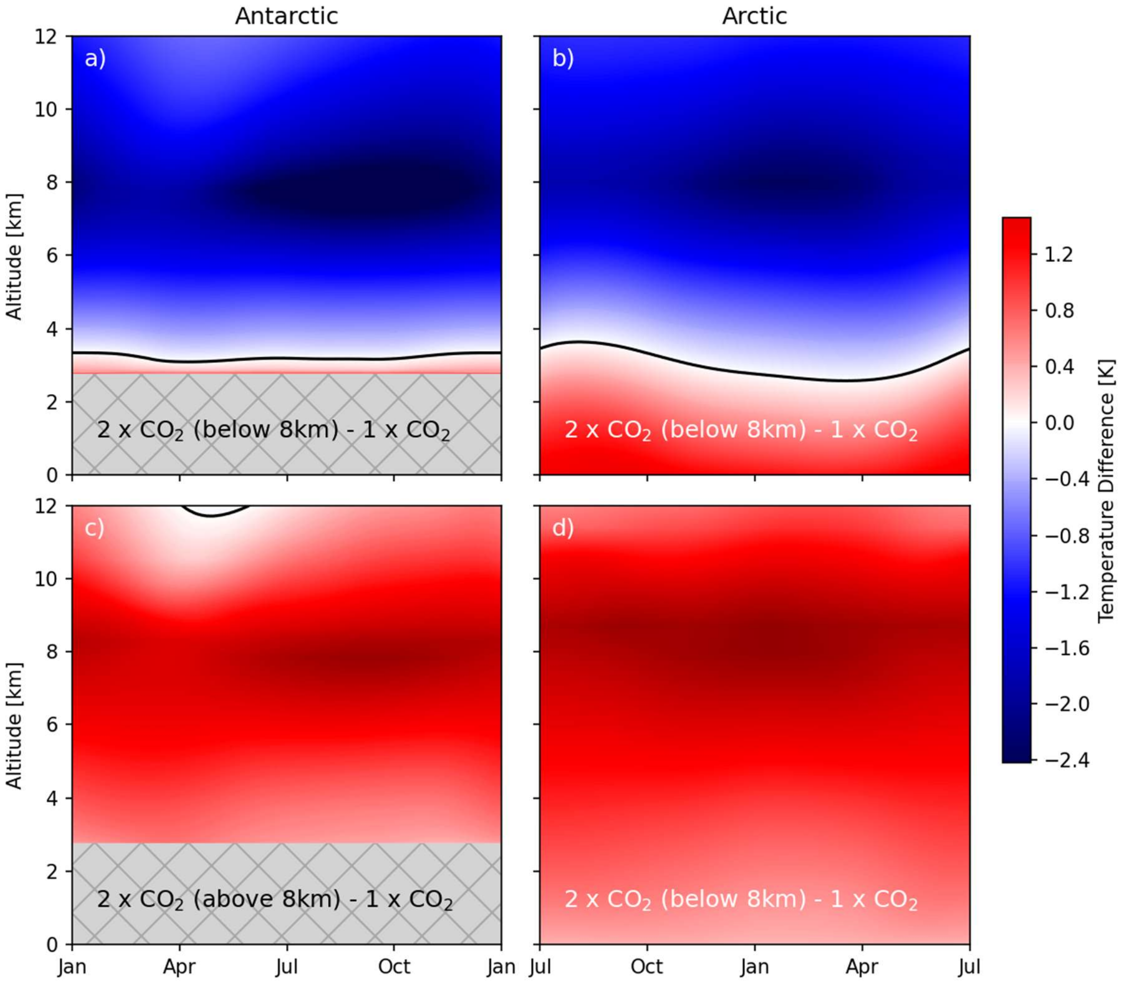

Figure S7: Temperature forcing (K) as a function of altitude throughout the year calculated for 2 x CO_2 - 1 x CO_2 for Antarctica (a and c) and the Arctic (b and d). CO_2 have been doubled up to 8 km (a and b) or above 8 km (c and d). In Antarctica the surface is at 2.8 km altitude, in the Arctic at 1 m.

References

Riihimaki, Laura; Long, Charles E; Dutton, Ellsworth G; Michalsky, Joseph (2023): Basic and other measurements of radiation at station South Pole (1992-01 et seq). NOAA Global Monitoring Laboratory, Boulder, PANGAEA, https://doi.org/10.1594/PANGAEA.956847.

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