A projected decrease in lightning under climate change

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Supplementary information for “A projected decrease in lightning under global warming”

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Calculation of the probability of lightning occurrence: The lightning parametrisation calculates a flash rate for each grid cell at every time step. Here we calculate the probability of lightning occurring (i.e. a flash rate greater than zero), in a grid cell and in a model time step. Each occurrence of a flash rate greater than zero counts as 1 in the calculation of probability.

$$P = \frac{\sum_{n=1}^{N} \sum_{t=1}^{T} L_{n,t}}{NT}$$

where N is the total number of grid cells, T is the total number of time steps. $L_{n,t} = 1$ if the flash rate in grid cell, n, and time step, t, is non-zero, or $L_{n,t} = 0$ otherwise. P is therefore the probability of any flashes occurring in a grid cell and model time step. If the flash rate distribution shifts to more or less intense flash rates then the total flashes can change independently of the change in probability of flashes.

Calculation of the uncertainty in total methane radiative forcing due to the uncertainty in LNO_x response to climate change: The prescribed methane concentration for the present-day simulation is 1750 ppbv, and for the year 2100 RCP8.5 simulation is 3750 ppbv. Using the method of calculating methane radiative forcing listed in the methods section[1], the RF between 2000 and 2100 of prescribed methane concentrations under RCP8.5 is 598 mW m^{-2}. The methane RF associated with the LNO_x response to climate change is -20.3 and +33.7 mW m^{-2} for the CTH and IFLUX schemes, respectively. This corresponds to approximately ±5% of the total methane radiative forcing between 2000 and 2100 RCP8.5.

Discussion of the potential for a transient sampling pressure level: With the time slice approach used in this study, it has been possible to calculate an appropriate sampling level for the future climate. However, for transient climate simulations an interactive sampling level is needed, and we provide some initial suggestions for this here.

The equation used to calculate the future sampling level in this study (see methods) can be applied to any time, t. The equation can be applied at each time step, or over longer timescales, such as yearly. Longer timescales might be helpful in reducing noise and make more efficient use of computational resources.

In determining the future sampling level we considered multiple approaches besides our main approach outlined in the Methods. All the approaches considered produced a future sampling level of 390 hPa ± 3 hPa. Considering instead a consistent temperature value, in the present-day simulation the mean temperature of the 440 hPa pressure level is ~250K and this same temperature occurs at 390 hPa in the future simulation. Alternatively, considering the relative position between the mean pressure of the 0°C and -40°C isotherms ($K_{2000} \approx 0.55$), instead of 0°C and the tropopause as used in the main approach, also suggested a future level of ~390 hPa was appropriate. In developing a method for transient climate simulations, these alternative reference levels could be used be used to calculate the sampling level.

References

1. Myhre, G., Highwood, E. J., Shine, K. P. & Stordal, F. New estimates of radiative forcing due to well mixed greenhouse gases. *Geophys. Res. Lett.* **25,** 2715–2718 (1998).

2. Hoerling, M. P., Schaack, T. K. & Lenzen, A. J. A global analysis of stratospheric–tropospheric exchange during northern winter. *Mon. Weather Rev.* **121,** 162–172 (1993).

Supplementary Tables

Table S1. Total annual flashes and probability of lightning occurrence in the tropics (±23° latitude) and extratropics (23°-90° latitude) for each simulation in the 2000s and 2100s. Percentage changes relative to 2000 for each approach are given in brackets. The probability metric represents the probability of lightning occurring in any given grid cell and hour over the course of the year. Results use a single year of simulation.

Simulation	Tropics		Extratropics	
	Total ($x10^8$ fl. yr^{-1})	Probability	Total ($x10^8$ fl. yr^{-1})	Probability
CTH-2000	10.9	0.056	3.07	0.021
CTH-2100	14.2 (+30.3%)	0.049 (-12.5%)	5.31 (+73.0%)	0.024 (+14.3%)
IFLUX-2000	9.29	0.059	4.87	0.036
IFLUX-2100	6.66 (-28.3%)	0.047 (-20.3%)	5.34 (+9.7%)	0.036 (+0.0%)
IFLUX440-2100	3.22 (-65.3%)	0.055 (-6.8%)	5.15 (+5.7%)	0.040 (+11.1%)

Table S2. Change in total annual flashes and atmospheric composition for the fixed sampling level simulation in the 2100s compared to the 2000s. Extension of Table 1 in the main text.

Simulation	Global lightning ($x10^9$ fl. yr^{-1})	Tropospheric ozone burden (DU)	Tropospheric ozone lifetime (days)	Methane lifetime (yrs)
IFLUX-2000	1.42	266	19.8	9.9
IFLUX440-2100	0.84 (-41%)	223 (-16%)	16.1 (-19%)	8.8 (-11%)

Table S3. Radiative forcing estimates in each set of simulations between year 2000 and year 2100 under RCP8.5, using the typical set of parameters given in the methods.

Simulation	CH_4 RF (mW m^{-2})	Total O_3 RF (mW m^{-2})	Net RF (mW m^{-2})
ZERO	-168.7	-140.5	-309.2
CTH	-189.0	-95.0	-284.0
IFLUX	-135.0	-177.5	-312.6
IFLUX440	-81.9	-228.7	-310.6

Supplementary Figures

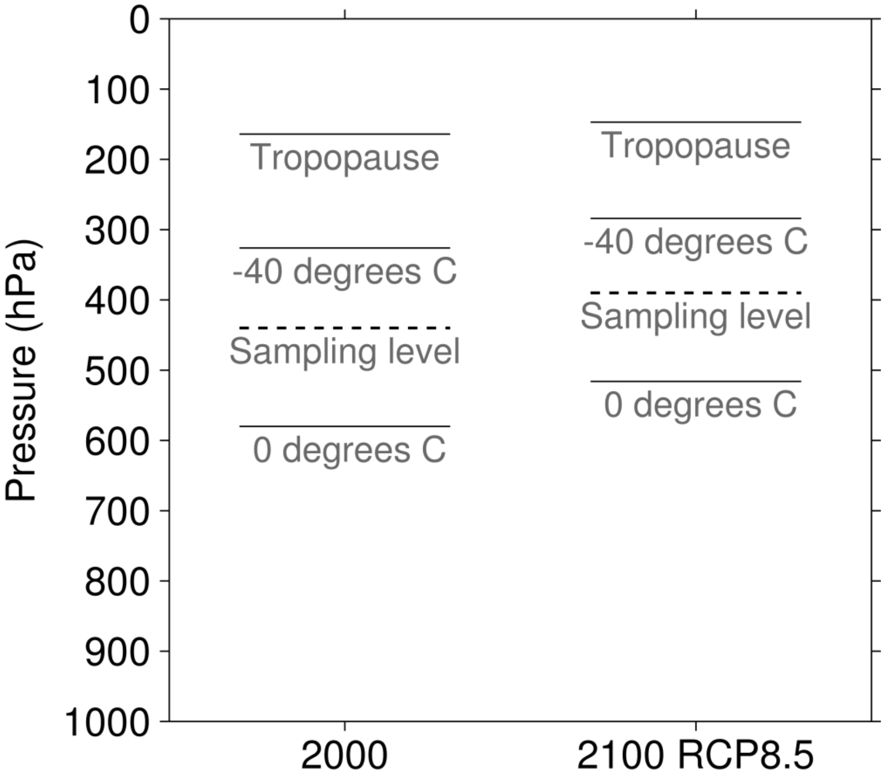

Figure S**1** Diagram illustrating the sampling levels used in the IFLUX scheme and relevant global mean pressure levels for features of the atmosphere, based on the first year of simulation for the present-day and future time periods.

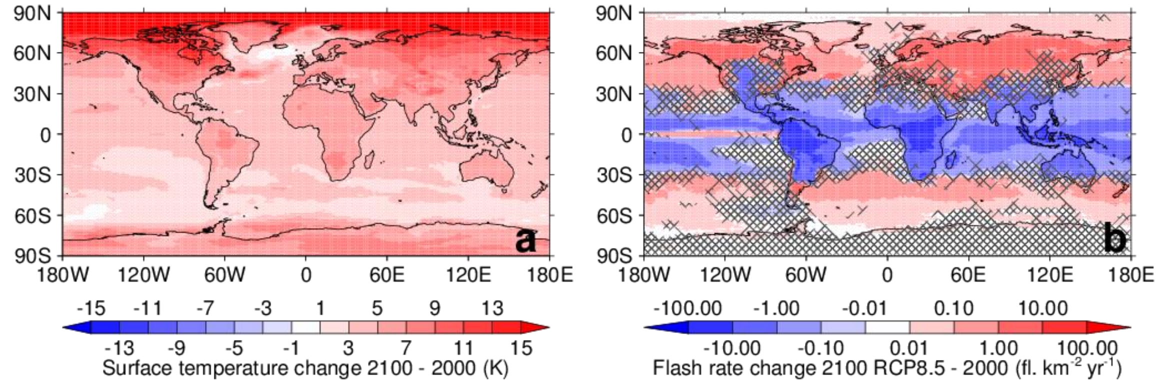

Figure S**2** Change in: (a) annual average surface temperature for all future simulations and (b) lightning flash rate using a fixed sampling level of 440hPa in both the future year 2100 and present-day year 2000 simulations. The change is calculated between the decadal mean for year 2000 and year 2100 RCP8.5. Hatching on (b) is where the change is not significant at the 5% level. The change in global mean surface temperature is +4.87K.

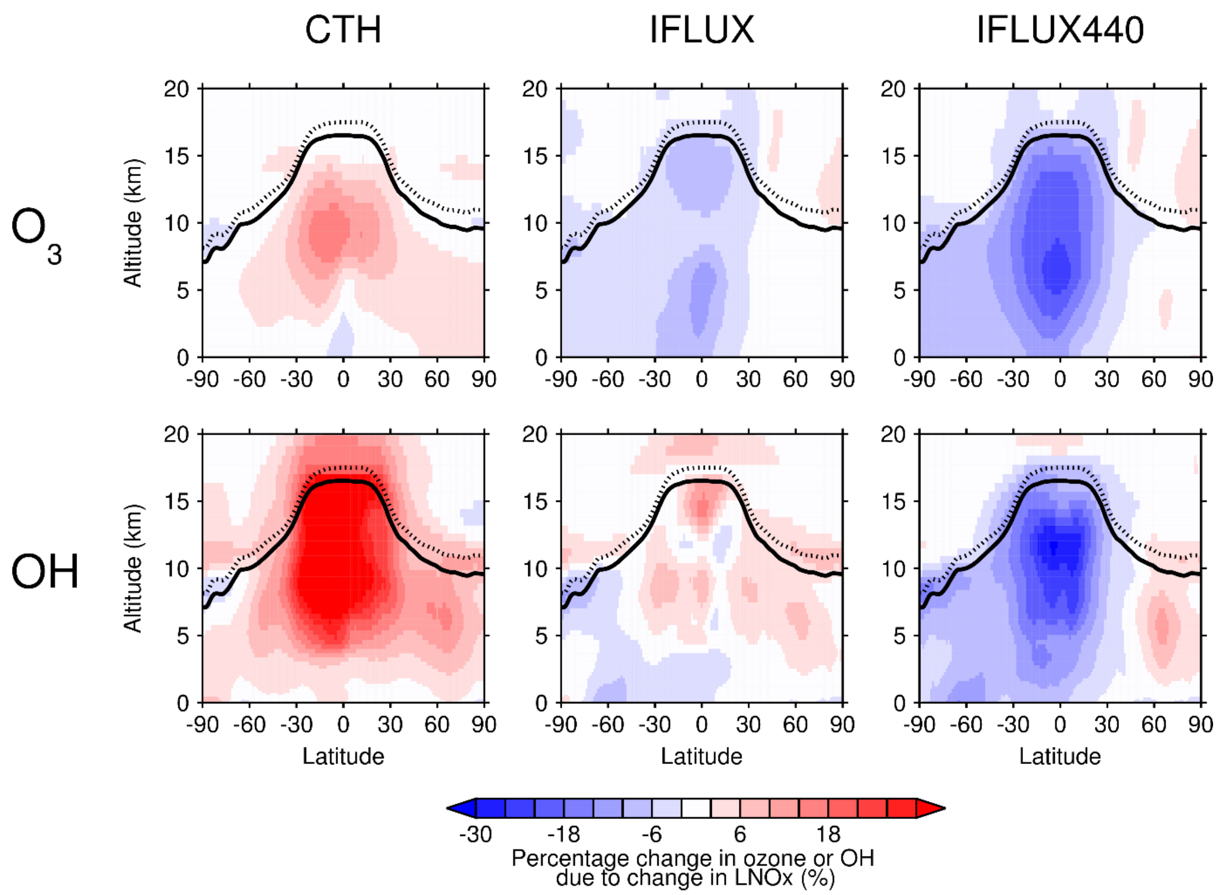

Figure S**3** Zonal mean percentage change in ozone mixing ratio, and OH concentration, between the 2000s and 2100s under RCP8.5 for the CTH and IFLUX approaches and the IFLUX440 sensitivity test. The direct effect of climate change has been removed by first subtracting the change in the ozone mixing ratio, and OH concentration, between the ZERO-2000 and ZERO-2100 simulations. The present-day (solid) and future (dotted) zonal annual mean tropopauses are shown. The dynamic tropopause is simulated in the model using a combined isentropic-dynamical definition[2].