Minimal climate impacts from short-lived climate forcers following emission reductions related to the COVID-19 pandemic

James Weber[1], Youngsub M. Shin[1], John Staunton Sykes[1], Scott Archer-Nicholls[1], Nathan Luke Abraham[1,2] and Alex T. Archibald[1,2]

[1]Centre for Atmospheric Science, Department of Chemistry, University of Cambridge, Cambridge, CB2 1EW, UK
[2]National Centre for Atmospheric Science, Department of Chemistry, University of Cambridge, Cambridge, CB2 1EW, UK

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Introduction

The following is supporting information for the main text. It consists of additional plots including parameters calculated from processing UKCA output data, additional emission reduction information, further detail as to the calculation of methane concentration perturbation and additional information about the species emitted in the UKCA model.
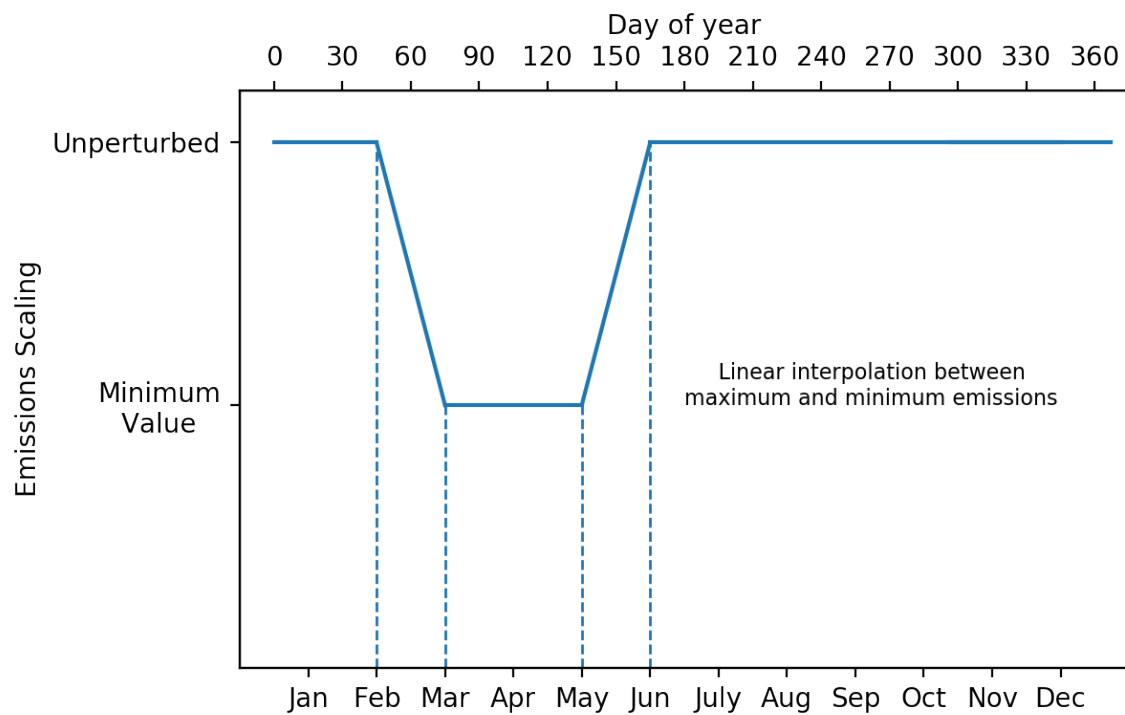
Figure S1. Emissions Time Series. Month ticks aligned to the middle of each month. Emitted values are updated every 5 days.
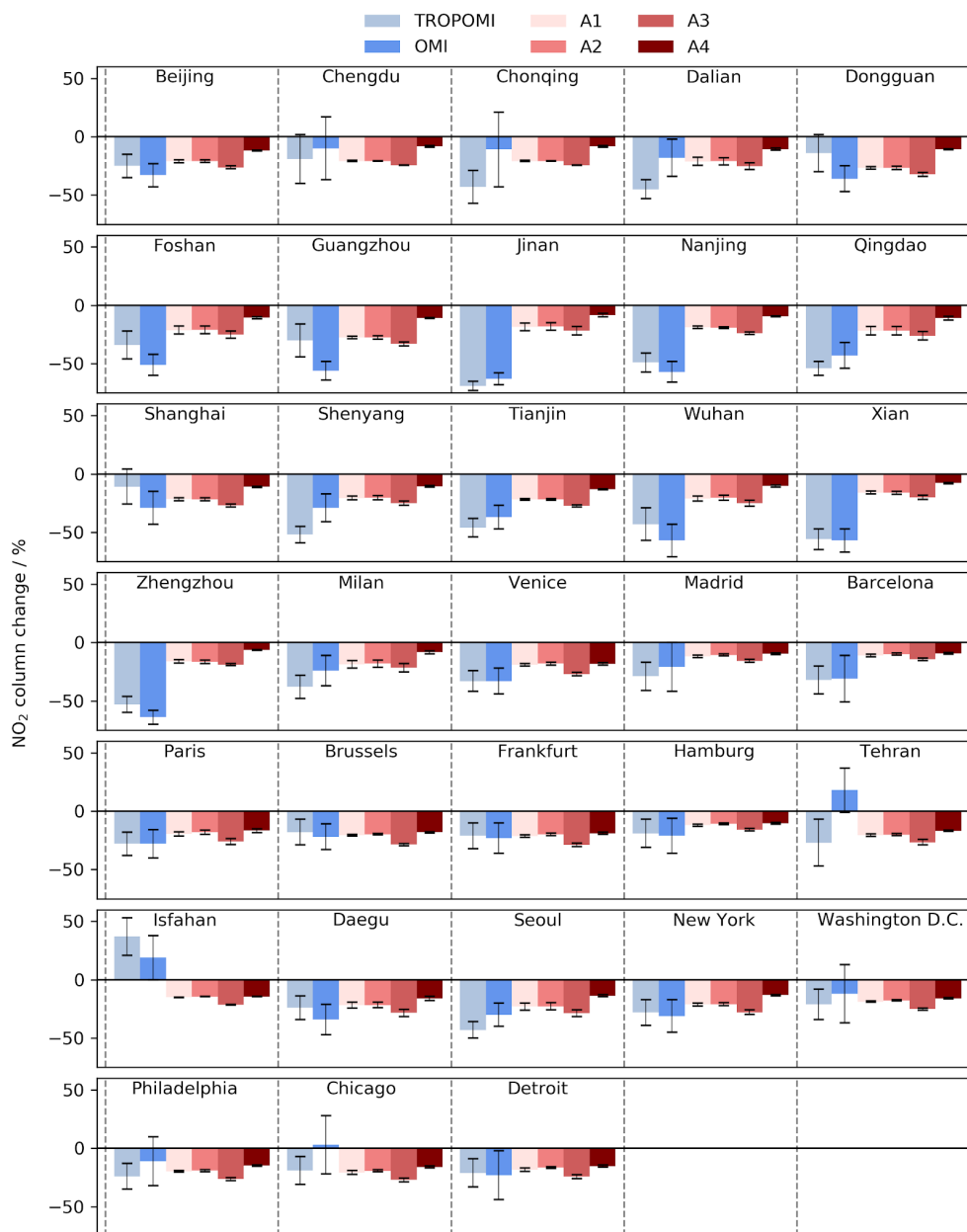
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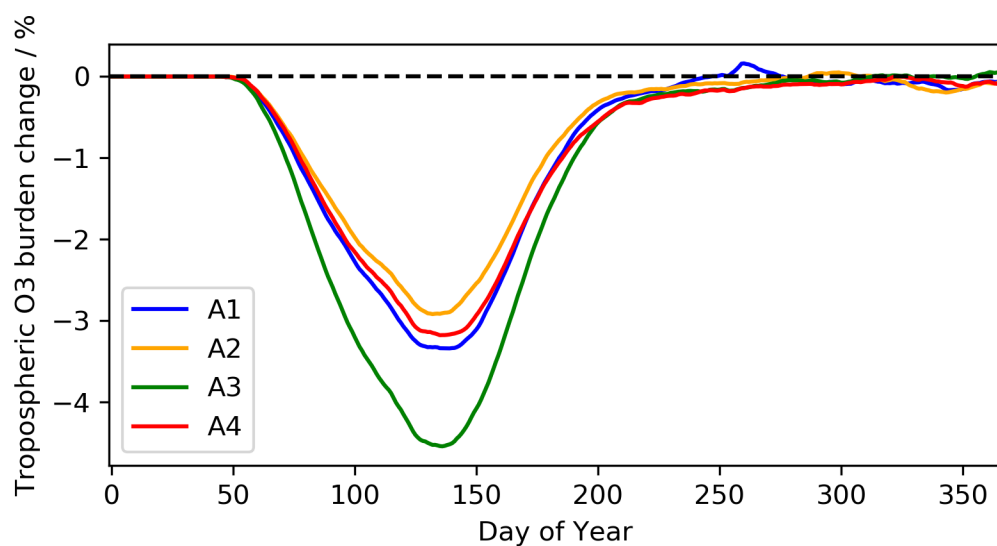
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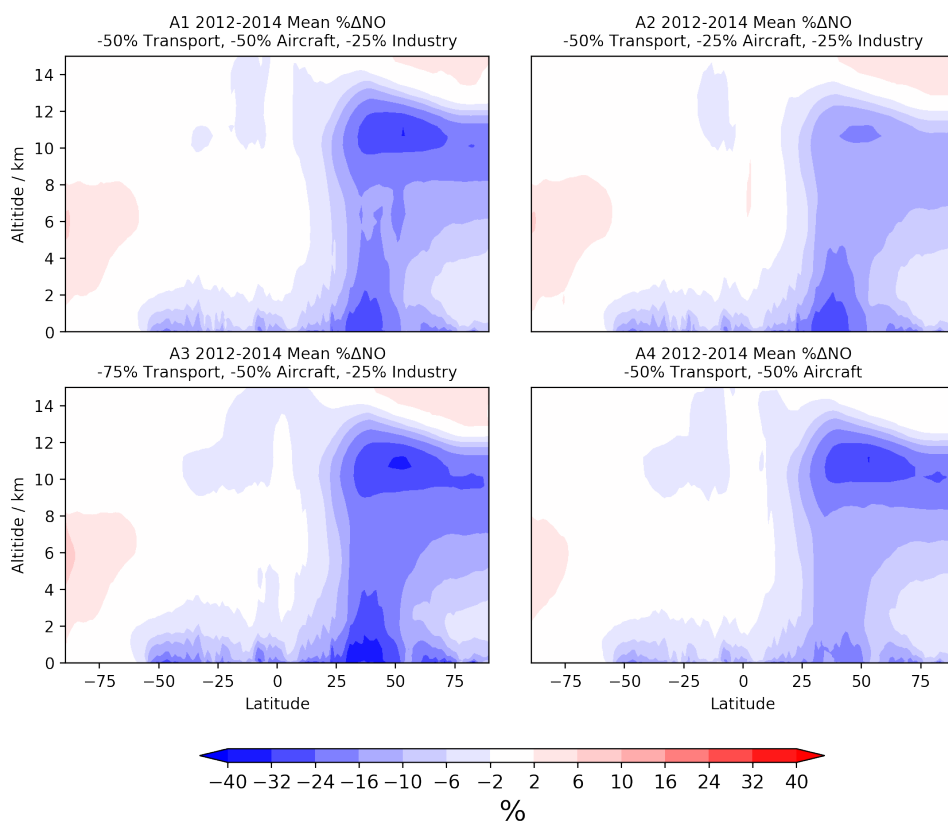
Figure S4. Zonal mean of percentage change in NO mixing ratio (mid March - mid May) averaged over 3 years 2012-2014.
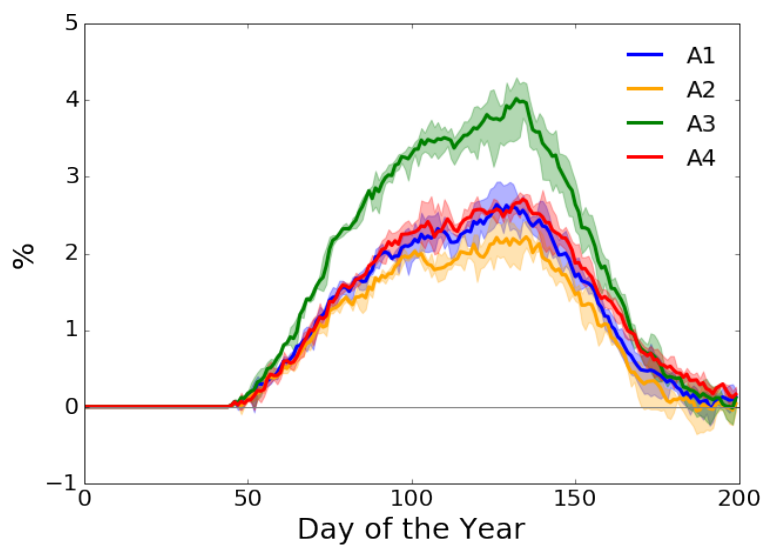

Figure S5. Percentage difference in global mean methane lifetime averaged over 3 years 2012-2014 (shading shows the ensemble range).
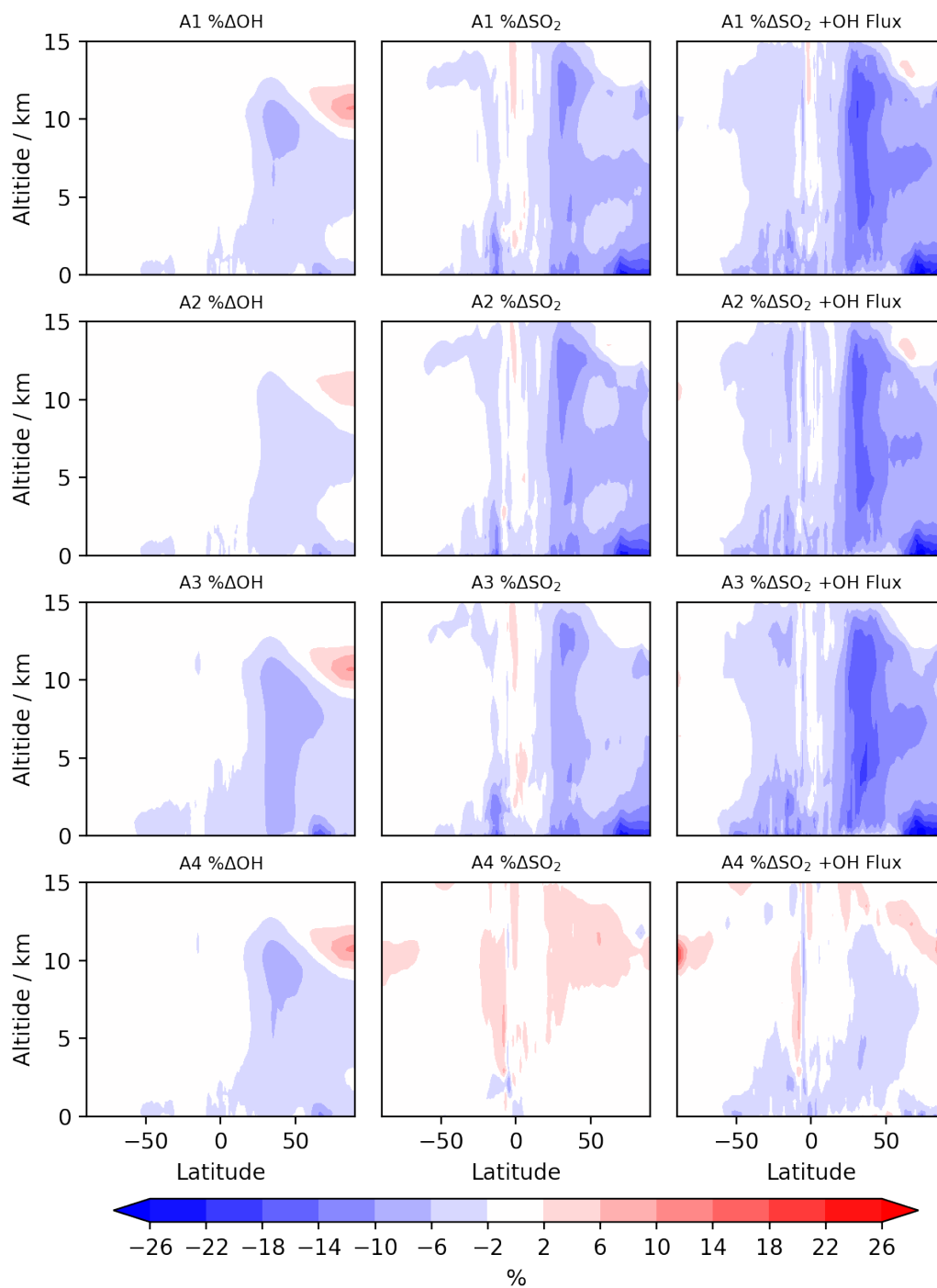
Figure S5. Zonal mean of percentage change in OH and SO₂ mixing ratios and SO₂ + OH flux (mid March - mid May) averaged over 3 years 2012-2014.
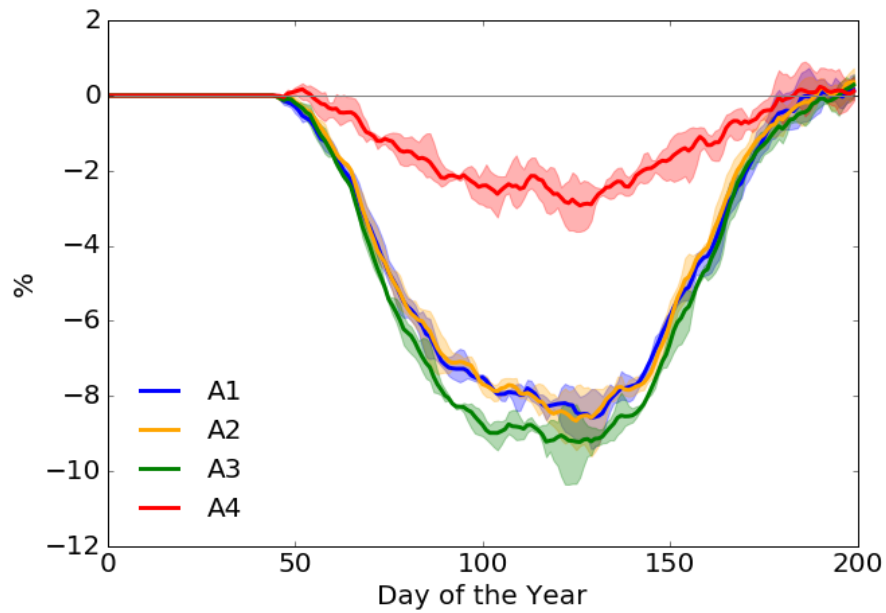
Figure S6. Percentage change time series in total sulfate burden averaged over 3 years 2012-2014. Shading shows ensemble range.
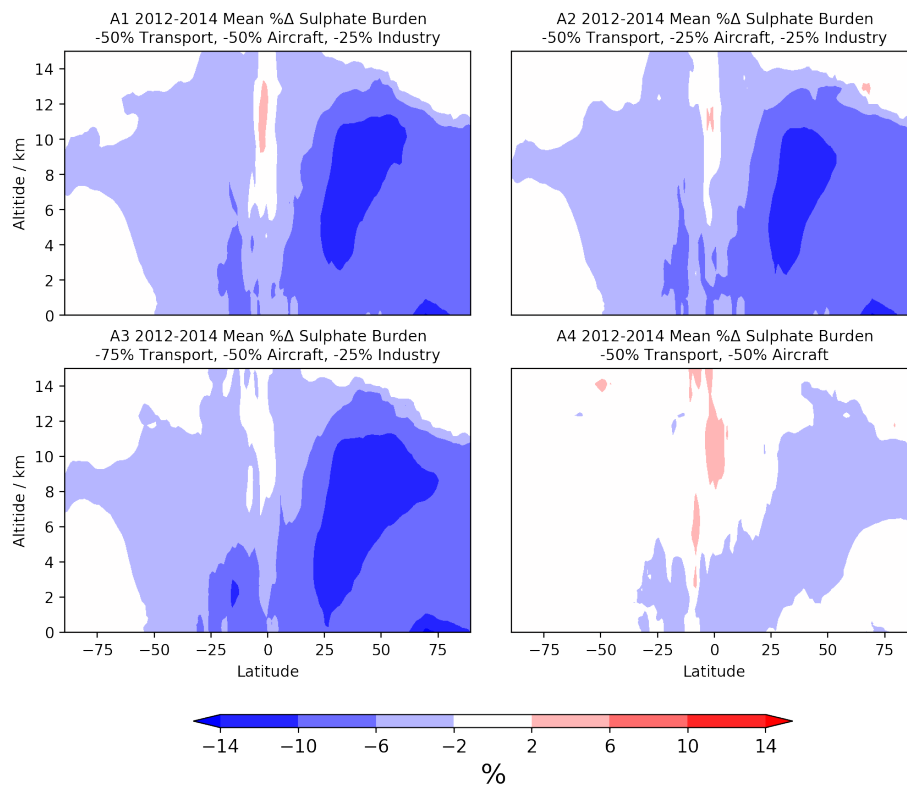

Figure S7. Zonal mean of percentage change in sulphate aerosol burden (mid March - mid May) averaged over 3 years 2012-2014.
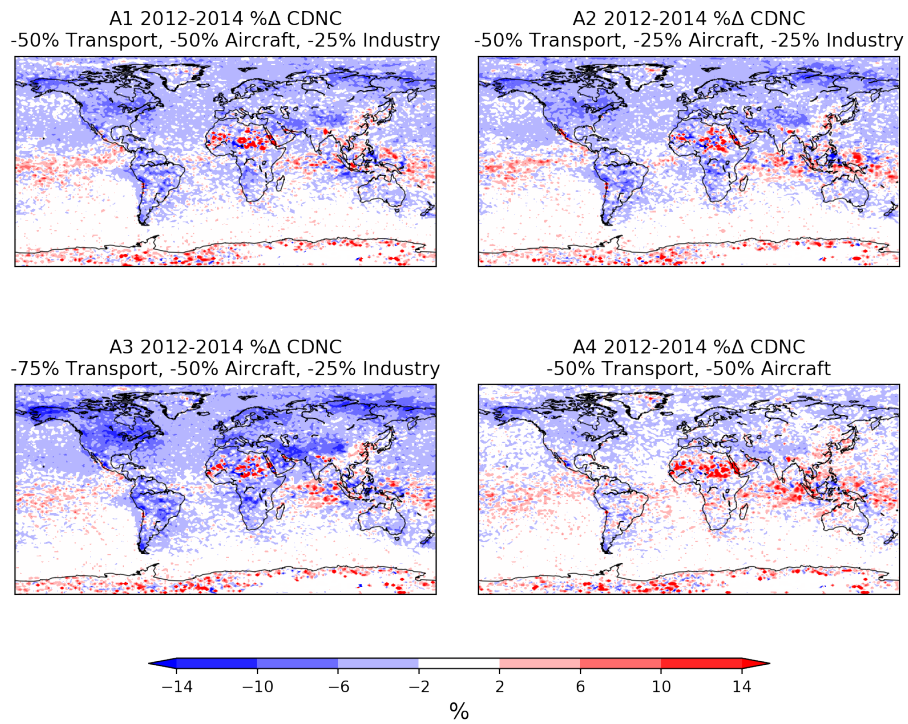
A1 2012-2014 %Δ CDNC
-50% Transport, -50% Aircraft, -25% Industry

A2 2012-2014 %Δ CDNC
-50% Transport, -25% Aircraft, -25% Industry

A3 2012-2014 %Δ CDNC
-75% Transport, -50% Aircraft, -25% Industry

A4 2012-2014 %Δ CDNC
-50% Transport, -50% Aircraft

Figure S8. Percentage change in CDNC for (mid March - mid May) averaged over 3 years 2012-2014.

A1 2012-2014
-50% Transport, -50% Aircraft, -25% Industry
Area-weighted Global Mean 0.352 %

A2 2012-2014
-50% Transport, -25% Aircraft, -25% Industry
Area-weighted Global Mean 0.365 %

A3 2012-2014
-75% Transport, -50% Aircraft, -25% Industry
Area-weighted Global Mean 0.456 %

A4 2012-2014
-50% Transport, -50% Aircraft
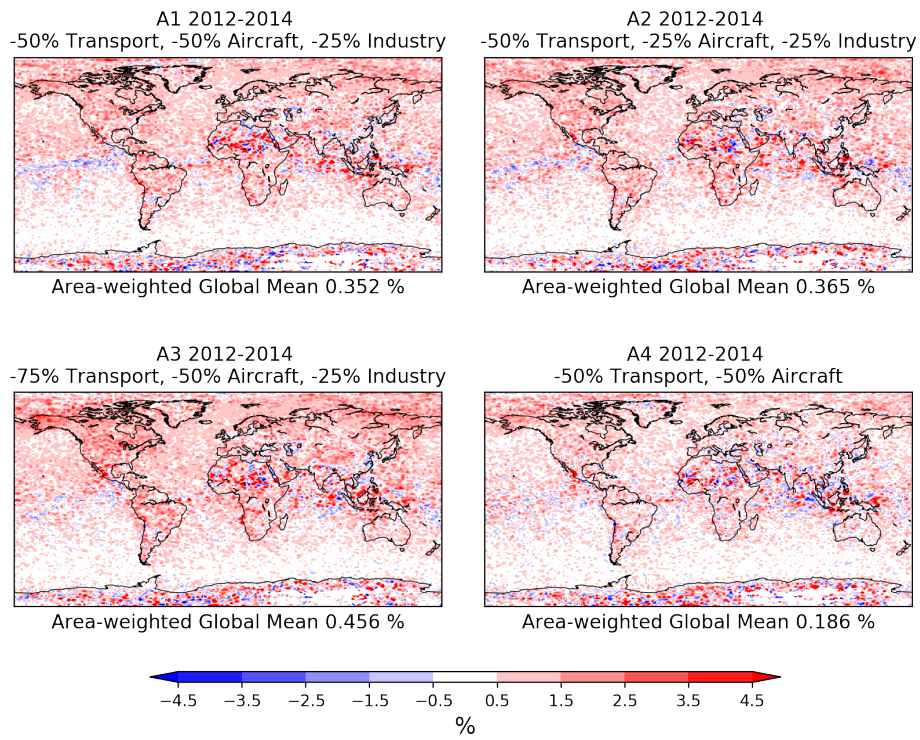Area-weighted Global Mean 0.186 %

Figure S9. Percentage change in cloud droplet effective radius (mid March - mid May) averaged over 3 years 2012-2014.
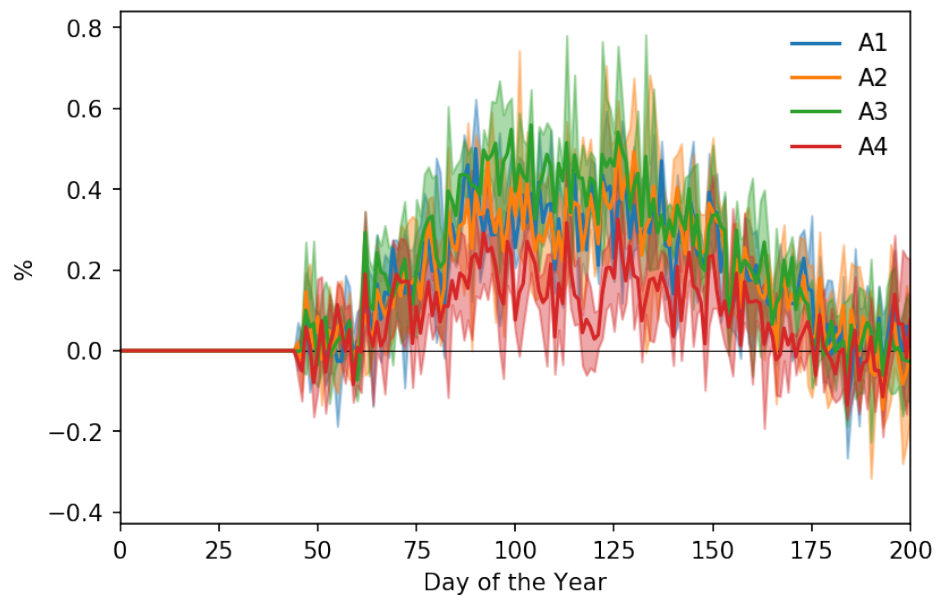

Figure S10. Area-weighted mean percentage change in cloud droplet effective radius (shaded region shows ensemble range). The rapid response to emissions decline and subsequent recovery is evident.
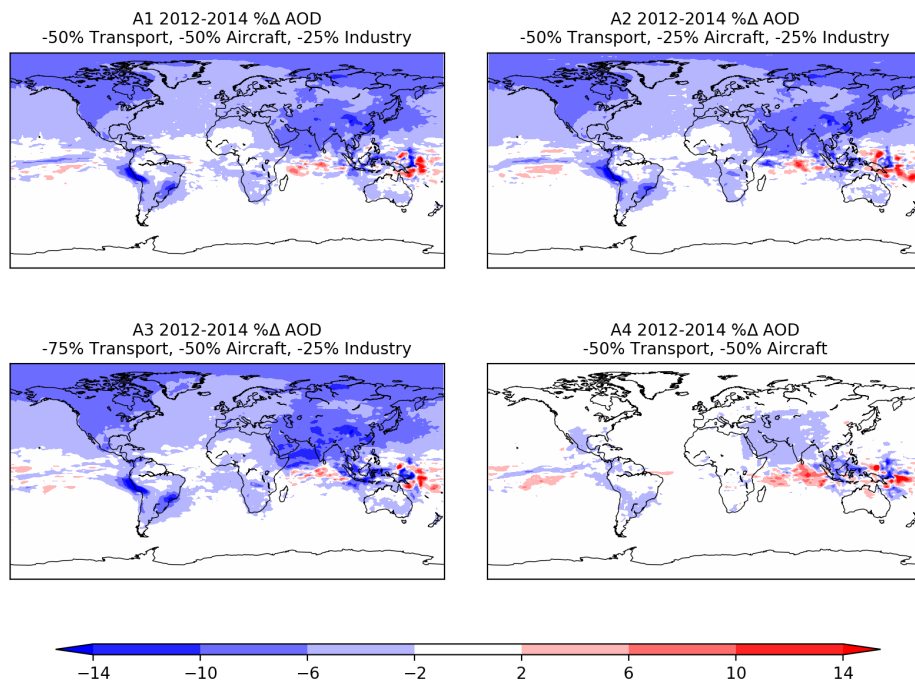

Figure S11. Percentage change in simulated AOD at 550 nm (mid March - mid May) averaged over the three years investigated.
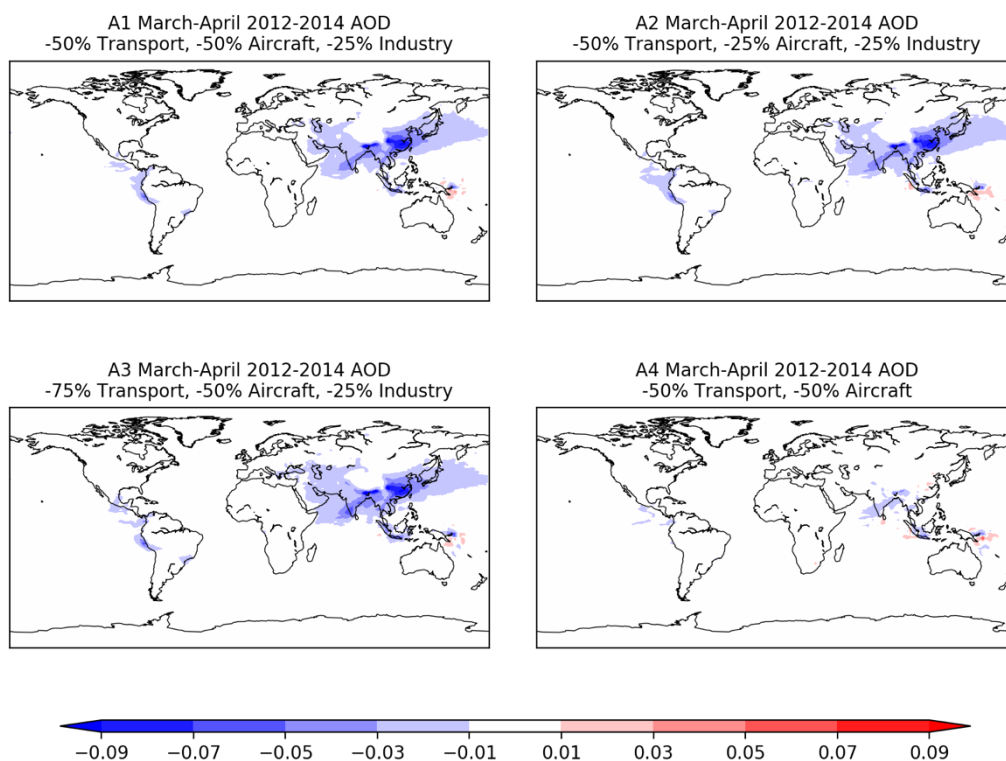
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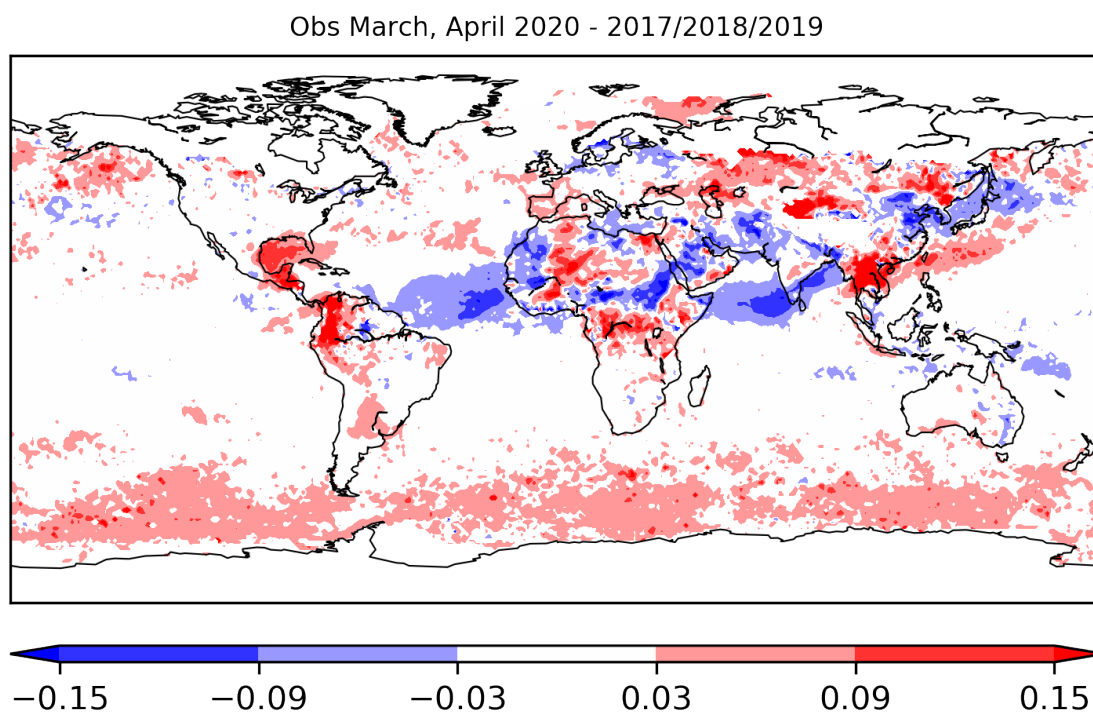
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Figure S16. Changes to emissions of black carbon (BC) for March - May averaged over 3 years 2012-2014.

Figure S17. Changes to emissions of SO₂ for March - May averaged over 3 years 2012-2014.

Text S1: Emission Scenario Description
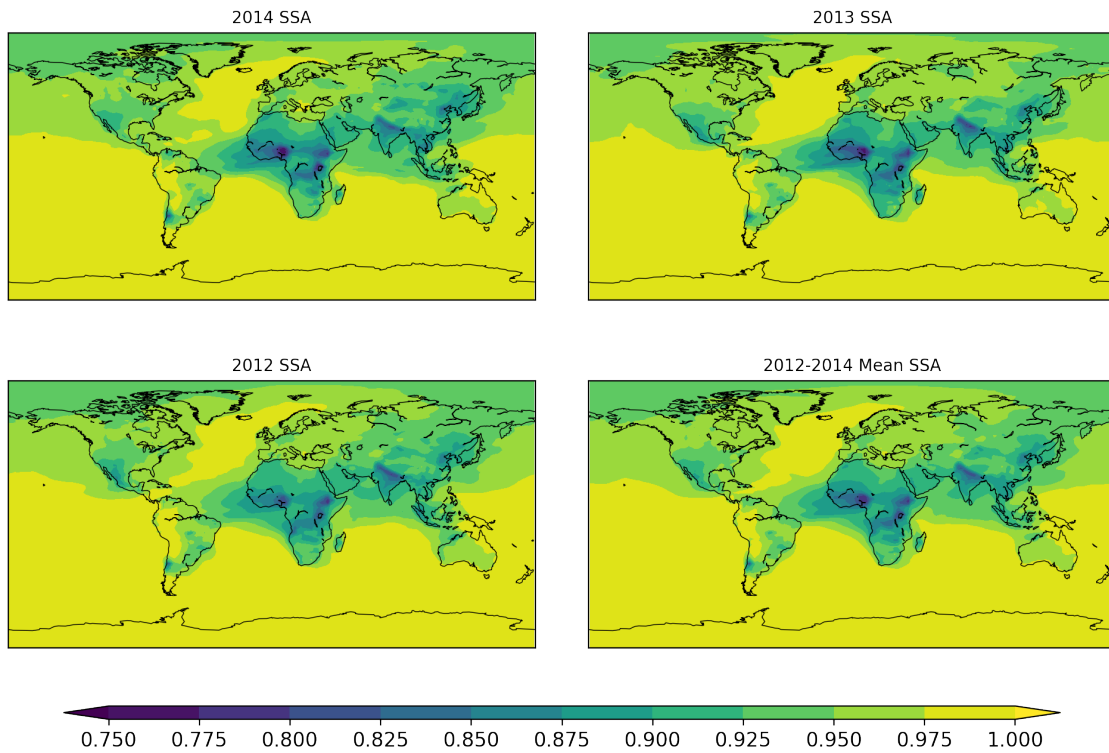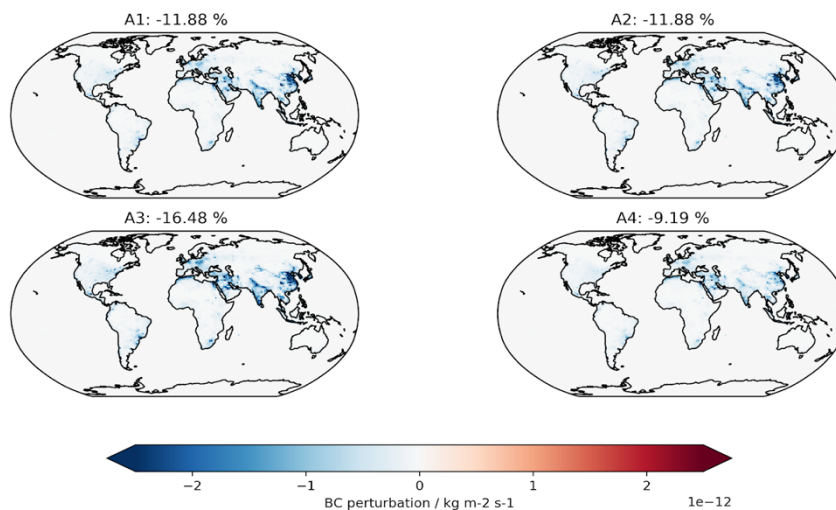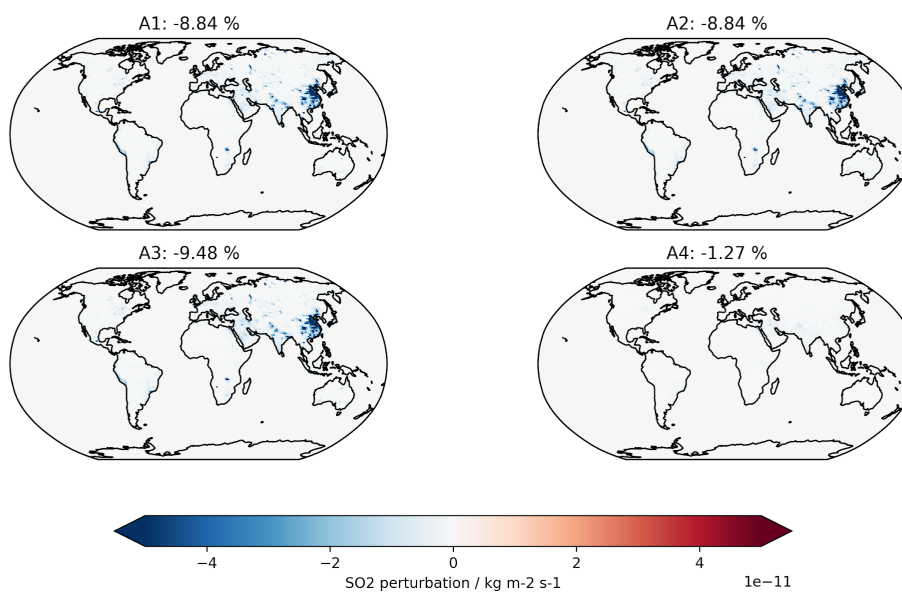
The emissions scenarios were conceptualised in late March/early April 2020 when verified data concerning the impact of lockdowns on anthropogenic sector emissions was not plentiful or widely available. In order to best estimate the reductions, we compiled information from several sources which are detailed below:

Lockdown measures resulted in an 88% decline in car use in the EU and a 60% decrease in industrial carbon emissions by 25th March (Mallet, 2020), the EEA reported that NO2 concentrations in several cities in southern Europe were around 50% lower than 2019 (European Environment Agency, 2020). In the UK, there was a 60% reduction in all motor vehicle use in the UK (UK Department of Transport, 2020).

International flights from the UK, USA, China, Germany and Japan have decreased 75% from January to the end of March this year (Kommenda, 2020), and european internal flights are estimated to have decreased by 86%. Data from Flightradar (FlightRadar, 2020) was also used to estimate a change in the total global flight by around 50%. Some uncertainty was present early on due to the 'ghost flights' berth requirements law, but the law was later suspended (Morgan, 2020).

The industrial sector was also hit by the COVID-19 lockdowns, but was a lot harder to quantify. It was suggested that EU industrial emissions decreased up to 60% [FT 2020],

Whilst it is likely that many other sectors were affected by the lockdowns, the data at the time provided insufficient evidence to come up with perturbations, so we did not attempt to estimate any of these changes. In this manner, our scenarios most likely represent a lower bound on the actual effect.

Text S2: Methane Concentration Evolution

To estimate the transient change in methane as a result of its lifetime perturbation, a simple kinetic model is considered with an instantaneous 4% increase in methane lifetime. This produces an upper bound estimate for methane concentration as the lifetime change in scenarios A1-A4 are not instantaneous and only one scenario, A3, reaches 4% (Fig. S5). Nevertheless, the results are informative.

In this model, the initial steady state concentration of methane, , is defined in terms of methane flux, , and its lifetime, :

$$[CH_4]_0 = F\tau_0$$

Upon an instantaneous perturbation of methane lifetime to perturbed value, , with an unchanged flux, the methane concentration ceases to be that given by the steady state expression and can be described by the following differential equation:

$$\frac{d[CH_4]}{dt} = F - \frac{1}{\tau}[CH_4$$

Solving this via separation of variables yields:

$$-\tau \ln \left|F - \frac{1}{\tau}[CH_4]\right| = t + c$$

Where c is the constant of integration.

Noting that at $t = 0$, $[CH_4] = [CH_4]_0$, the constant of integration, c, can be written as

$$c = -\tau \ln \left|F - \frac{1}{\tau}[CH_4]_0\right|$$

This yields:

$$-\tau \ln \left|F - \frac{1}{\tau}[CH_4]\right| = t - \tau \ln \left|F - \frac{1}{\tau}[CH_4]_0\right|$$

Dispensing with the moduli and multiplying by $-\tau$ yields:

$$\ln \left(F - \frac{1}{\tau}[CH_4]\right) = -\frac{t}{\tau} + \ln \left(F - \frac{1}{\tau}[CH_4]_0\right)$$

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$$F - \frac{1}{\tau}[CH_4] = e^{-\frac{t}{\tau}}(F - \frac{1}{\tau}[CH_4]_0)$$

$$\frac{1}{\tau}[CH_4] = F - e^{-\frac{t}{\tau}}(F - \frac{1}{\tau}[CH_4]_0)$$

$$\frac{1}{\tau}[CH_4] = F(1 - e^{-\frac{t}{\tau_0}}) - \frac{1}{\tau}[CH_4]_0 e^{-\frac{t}{\tau_0}}$$

$$[CH_4] = F\tau(1 - e^{-\frac{t}{\tau_0}}) - [CH_4]_0 e^{-\frac{t}{\tau_0}}$$

Noting that $[CH_4]_0 = F\tau_0$

$$[CH_4] = F\tau(1 - e^{-\frac{t}{\tau_0}}) - F\tau_0 e^{-\frac{t}{\tau_0}}$$

The ratio, r, of perturbed $[CH_4]$ to original $[CH_4]_0$ can be expressed as:

$$r = \frac{[CH_4]}{[CH_4]_0} = \frac{F\tau(1 - e^{-\frac{t}{\tau_0}}) - F\tau_0 e^{-\frac{t}{\tau_0}}}{F\tau_0} = \frac{\tau(1 - e^{-\frac{t}{\tau}})}{\tau_0} - e^{-\frac{t}{\tau}}$$

This ratio satisfies the requirements:

$$\text{At } t = 0, r = 1$$

$$\text{As } t \to 0, r \to \frac{\tau}{\tau_0}$$

The ratio depends weakly on the initial methane lifetime, but it is clear that several decades are needed for the model to reach a new steady state concentration (Fig. S18). A 4% instantaneous increase in methane lifetime after 3 months, the length of the simulated perturbation, will result in a 0.1% increase in methane concentrations.
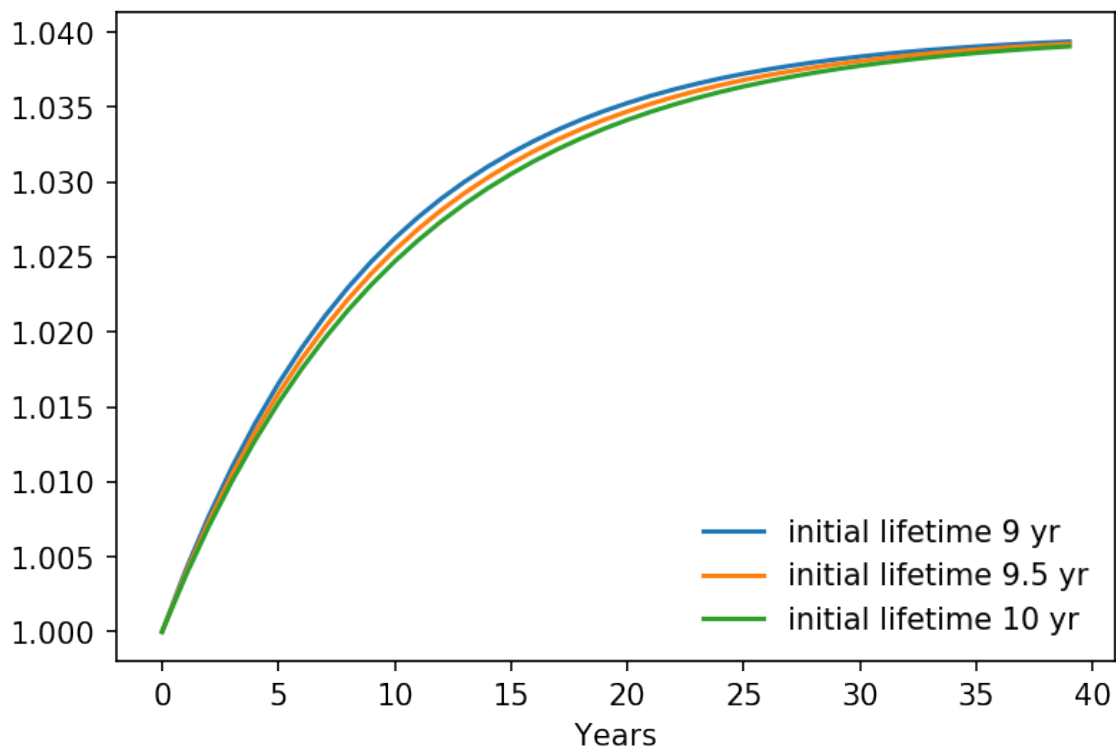
Figure S18. Ratio of perturbed methane concentration to initial methane concentration after an instantaneous increase in methane lifetime of 4% using the simple kinetic framework. Three initial methane lifetimes were considered.

Table S1. Emitted Species

Species
Black carbon
Organic carbon
NO
SO_2
C_2H_6
C_3H_8
HCHO
$(CH_3)_2CO$
CH_3CHO
CH_3OH
Other Organic
NH_3