Supporting Information for "Can reducing black carbon and methane below RCP2.6 levels keep global warming below 1.5 ºC ?"

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Appendix S1: HadGEM2-ES model description

HadGEM2-ES is the Earth-system model developed by the Met Office Hadley Centre and used for CMIP5 (HadGEM2 Development Team, 2011; Collins *et al.*, 2011). The atmosphere component has 38 levels up to approximately 40 km with a horizontal resolution of 1.25° in latitude by 1.875° in longitude. The ocean component has 40 levels with a resolution of 1° increasing smoothly to 1/3° from 30°N/S to the equator. The model includes components to simulate sea-ice, land surface processes and hydrology, the terrestrial carbon cycle, ocean biogeochemistry, atmospheric chemistry and aerosols.

BC aerosols derive from incomplete combustion and warm climate primarily through absorption of solar radiation (*e.g.*, Bond and Sun, 2005). Aerosols in HadGEM2-ES are simulated by the CLASSIC aerosol scheme (Bellouin *et al.*, 2011) which simulates BC as an external mixture of three modes representing fresh, aged and in-cloud aerosol particles. BC is considered to be hydrophobic and does not nucleate cloud droplets, the transfer to the in-cloud mode being via diffusional scavenging. Emission, transport, wet and dry deposition processes are all simulated as described in Bellouin *et al.* (2011).

The simulation of methane in HadGEM2-ES (Collins *et al.*, 2011) is performed by a tropospheric chemistry configuration of the UKCA model (O'Connor *et al.*, 2014). This uses 26 chemical tracers to model tropospheric NO_x-HO_x-CH_4-CO-O_x chemistry along with some representation of non-methane hydrocarbons (Collins *et al.*, 2011; O'Connor *et al.*, 2014). Oxidation impacts on stratospheric water vapour are not included. Changing methane emissions were simulated using prescribed time-varying surface concentrations as a boundary condition, with concentrations aloft modelled interactively. The radiation scheme does not take account of shortwave absorption by methane as it is considered to be of only minor importance.

Appendix S2: Effects of overshooting the 1.5 ºC target

A concern about scenarios such as meth2pc is how closely a climate which is returning to 1.5 ºC above pre-industrial after overshooting this target resembles a climate in which the target was never exceeded. We therefore compare two 10-year periods from the meth2pc simulation: 2024-2033, when 10-year mean temperature first reaches 1.5 ºC above pre-industrial, and 2068-2077, when 10-year mean temperature returns to the 1.5 ºC level after exceeding it for over 40 years.

Figure S2.1 shows the change in temperature between these two periods. Residual warming is evident over high latitude North America and also over the Arctic Ocean, especially the Barents and Kara Seas. There is also a mixture of warmer and cooler areas in the Southern Ocean, an area of considerable variability. However, most of the globe between about 60ºN and 60ºS shows little significant change, with differences less than 0.5 ºC. The only exception is north-east India where warming is in the 0.5-1.0 ºC range.

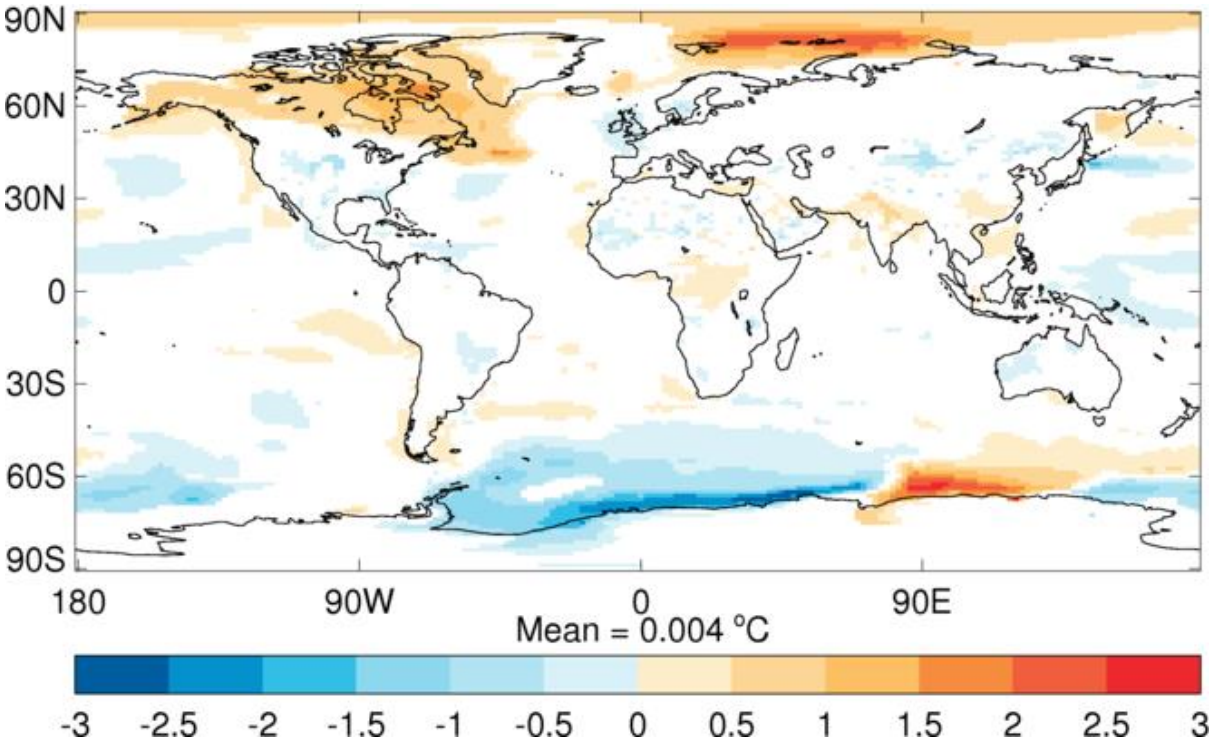

Figure S2.1 Difference in near-surface air temperature (ºC) between two 10-year periods in meth2pc when the global-mean temperature in both is 1.5 ºC above the pre-industrial level (2068-2077 minus 2024-2033). Areas where differences are not significant at the 5% level are left white.

Figure S2.2 shows the change in precipitation rate over land between the same periods. Precipitation rate is greater over parts of China and South-East Asia, and there is some indication of precipitation reduction in north-east India, but other than that there is little change. The distribution of changes in precipitation minus evaporation is very similar.

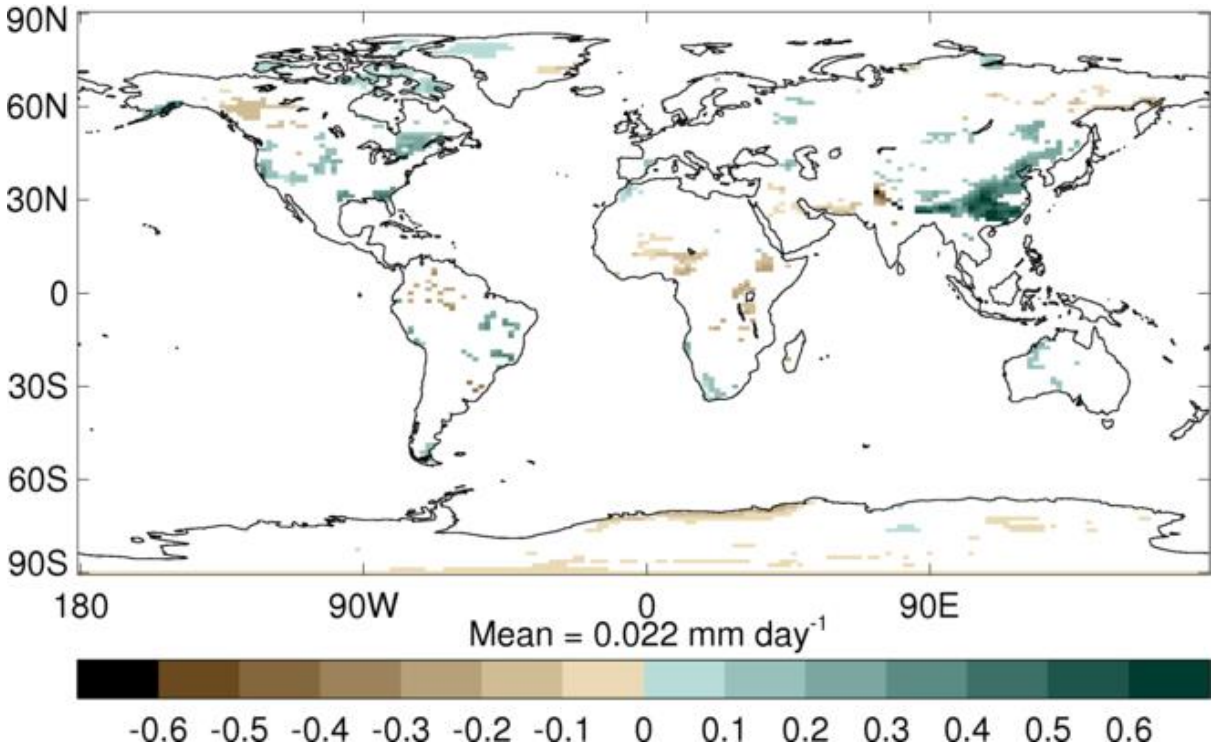

Figure S2.2 As Fig. S2.1 but for changes in precipitation rate over land (mm day^{-1}).

Figure S2.3 shows the changes in Arctic sea-ice area. As indicated by the changes in temperature at high latitudes (Fig. S2.1), the 40-year overshoot has caused a decrease in Arctic sea-ice compared with not exceeding the 1.5 ºC target, reducing annual-mean cover by almost 0.6 million km^2.

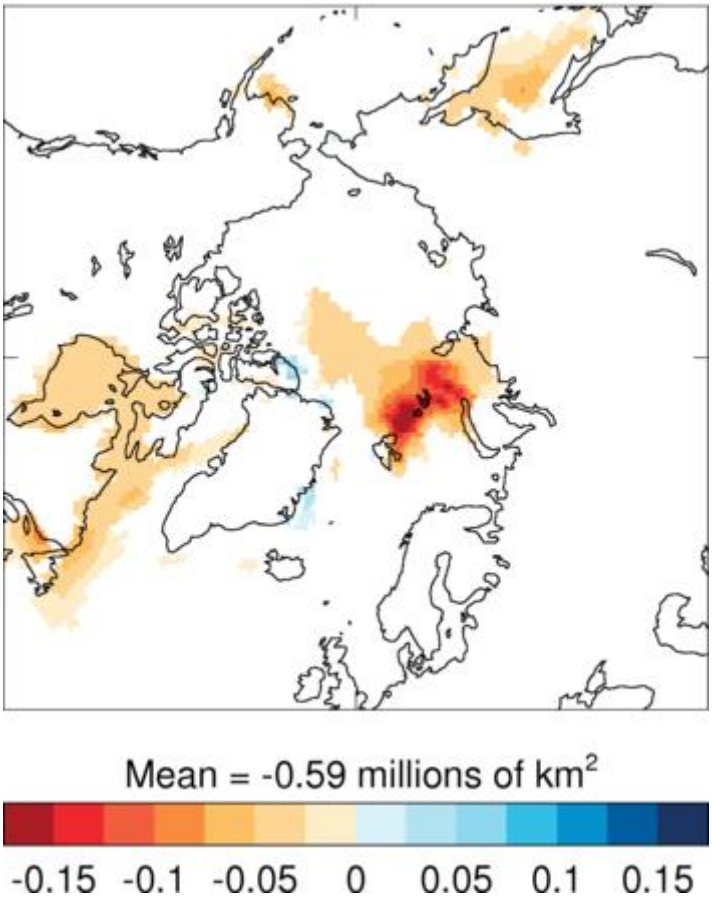

Figure S2.3 As Fig. S2.1 but for changes in Arctic sea-ice fraction (0-1) for each ocean grid-cell.

The difference in the net primary productivity (NPP) of land vegetation is shown in Figure S2.4. Due to the elevated levels of CO_2 during the overshoot period there is a general fertilization effect on vegetation, as well as possible effects from increased precipitation in SE Asia and high-latitude warming in North America. One notable area where NPP is reduced is the north-east of India, which is both drier and warmer in 2068-2077 compared with 2024-2033.

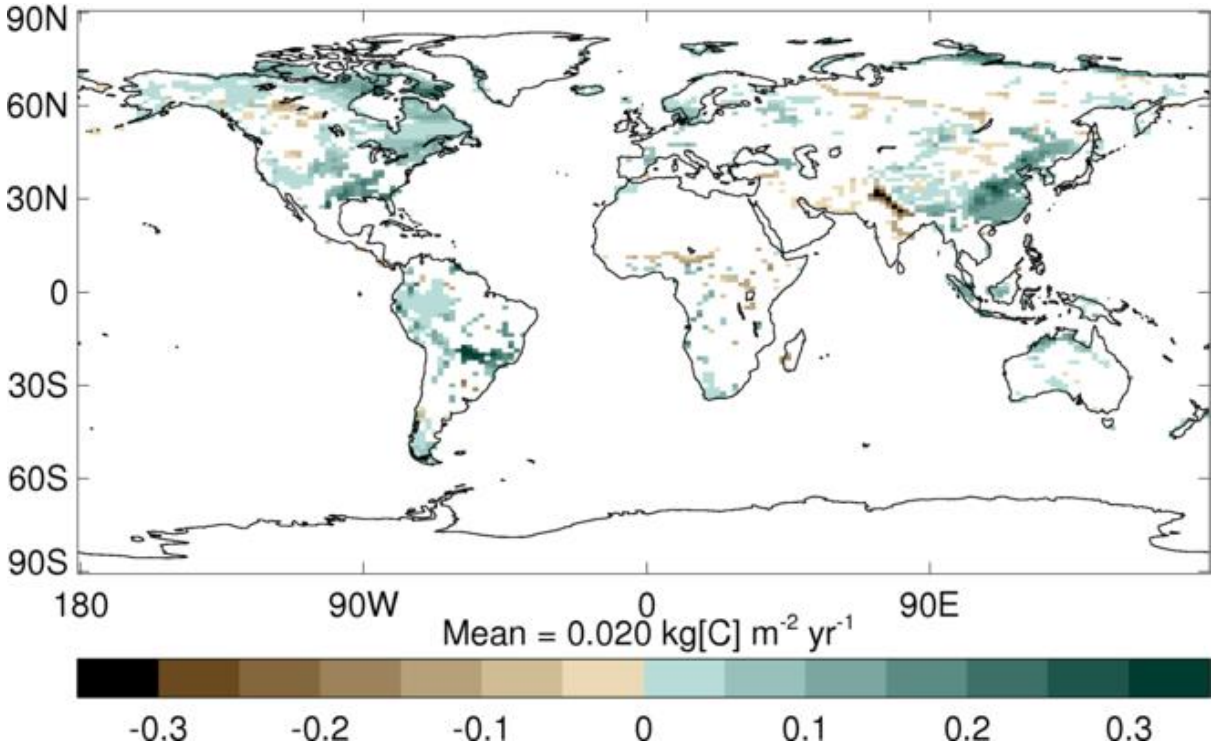

Figure S2.4 As Fig. S2.1 but for changes in vegetation net primary productivity (kg of carbon m^{-2} $year^{-1}$).

Appendix S3: Methane emissions

To infer methane emissions from a pathway (time evolution) of atmospheric methane concentration we construct a simple box model of global methane concentration which links surface emissions (E, anthropogenic and natural), atmospheric concentrations ($[CH_4]$) and atmospheric lifetime (τ) by assuming a relationship:

$$d[CH_4]/dt = E_{anth} + E_{nat} - [CH_4]/\tau \qquad \text{(Eq. S3.1)}$$

We assume fixed natural methane emissions of 180 Tg/year and a constant lifetime of 10.14 years. These values are calibrated so that the simple model approximately recreates the methane concentration pathways of the CMIP5 Historical and four RCP scenarios created by the MAGICC model (Meinshausen *et al*., 2011), minimizing the RMS errors between them. The results of the comparison are shown in Figure S3.1.

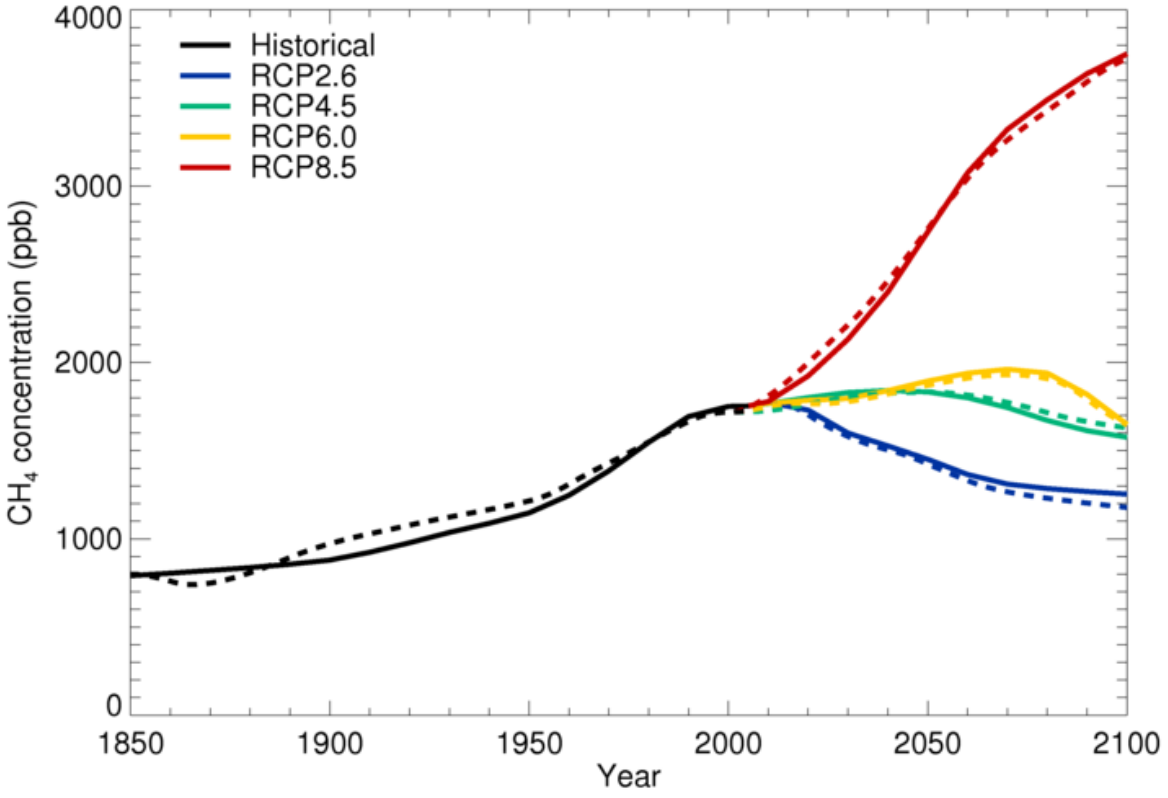

Figure S3.1 Surface methane concentrations (parts per billion) produced by MAGICC for the CMIP5 Historical and RCP scenarios (solid lines) compared with those predicted from the same input data by our simple model (Eq. S3.1; dashed lines).

In reality a positive feedback exists whereby more methane leads to an increased lifetime and hence a greater impact of methane emissions. However, an offsetting negative feedback also occurs whereby the induced greenhouse-gas warming reduces methane lifetime. Figure S3.1 shows that, for global-scale methane concentrations and emissions, neglecting both of these feedbacks, along with other components of atmospheric composition, does not lead to a systematic deviation from the relationship obtained by MAGICC. This holds equally for high as well as low emissions scenarios, and for increasing as well as decreasing concentration pathways.

Starting from a given pathway of atmospheric methane concentration, the anthropogenic emissions (E_{anth}) can be calculated as a residual of the prescribed concentration pathway, the natural emissions and the atmospheric chemical loss rate by rearranging equation S3.1.

References

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