8SM

Anthropogenic and Natural Radiative Forcing

Supplementary Material

Coordinating Lead Authors:

Gunnar Myhre (Norway), Drew Shindell (USA)

Lead Authors:

François-Marie Bréon (France), William Collins (UK), Jan Fuglestvedt (Norway), Jianping Huang (China), Dorothy Koch (USA), Jean-François Lamarque (USA), David Lee (UK), Blanca Mendoza (Mexico), Teruyuki Nakajima (Japan), Alan Robock (USA), Graeme Stephens (USA), Toshihiko Takemura (Japan), Hua Zhang (China)

Contributing Authors:

Borgar Aamaas (Norway), Olivier Boucher (France), Stig B. Dalsøren (Norway), John S. Daniel (USA), Piers Forster (UK), Claire Granier (France), Joanna Haigh (UK), Øivind Hodnebrog (Norway), Jed O. Kaplan (Switzerland/Belgium/USA), George Marston (UK), Claus J. Nielsen (Norway), Brian C. O'Neill (USA), Glen P. Peters (Norway), Julia Pongratz (Germany), Michael Prather (USA), Venkatachalam Ramaswamy (USA), Raphael Roth (Switzerland), Leon Rotstayn (Australia), Steven J. Smith (USA), David Stevenson (UK), Jean-Paul Vernier (USA), Oliver Wild (UK), Paul Young (UK)

Review Editors:

Daniel Jacob (USA), A.R. Ravishankara (USA), Keith Shine (UK)

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8.SM.1 Figures on Regional Emissions to Support Section 8.2.2

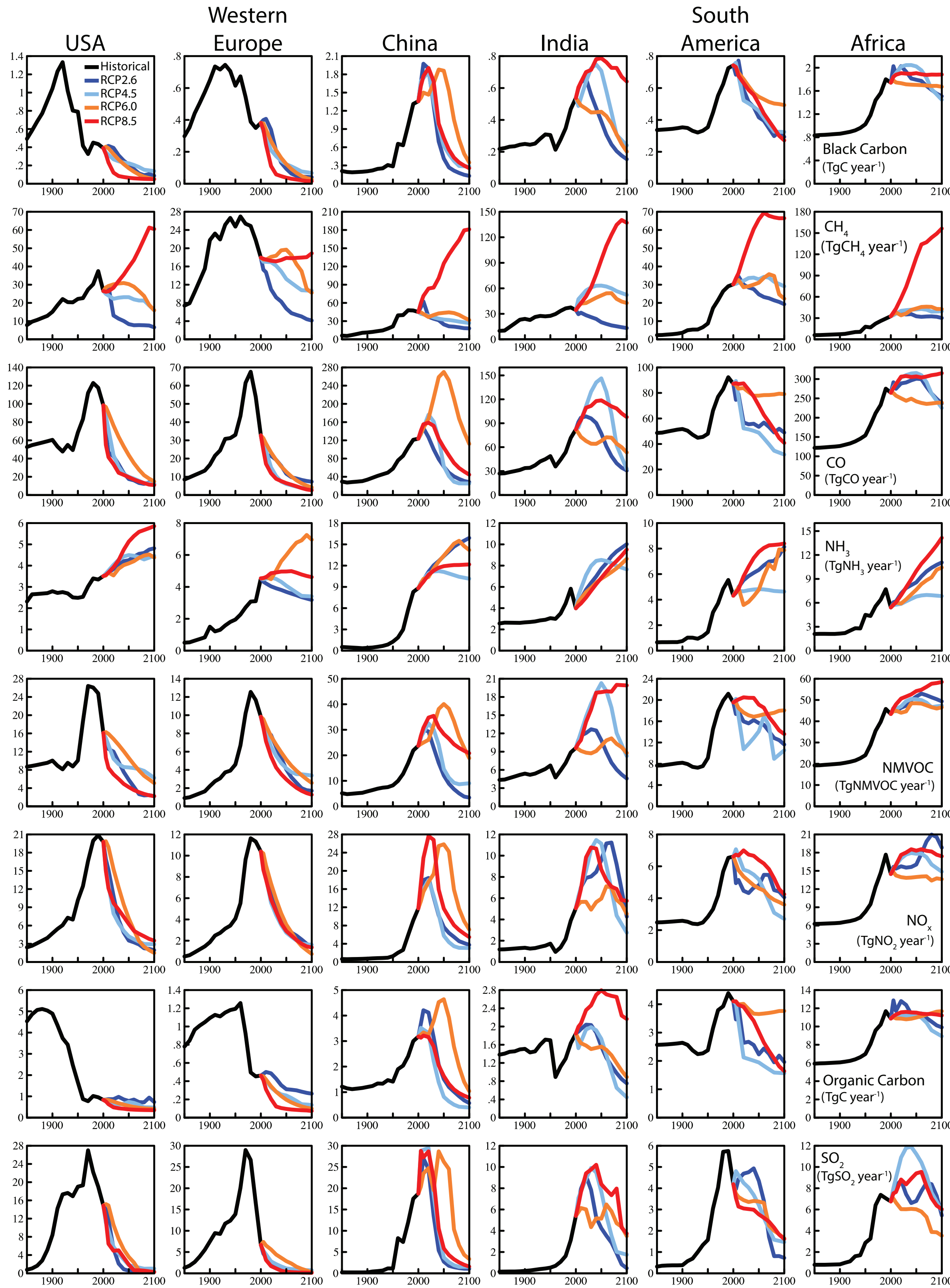

Figure 8.SM.1 | Time evolution of regional anthropogenic and biomass burning emissions 1850–2100 used in Coupled Model Intercomparison Project Phase 5 (CMIP5)/Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP) following each Representative Concentration Pathway (RCP). Historical (1850–2000) values are from (Lamarque et al., 2010). RCP values are from (van Vuuren et al., 2011).

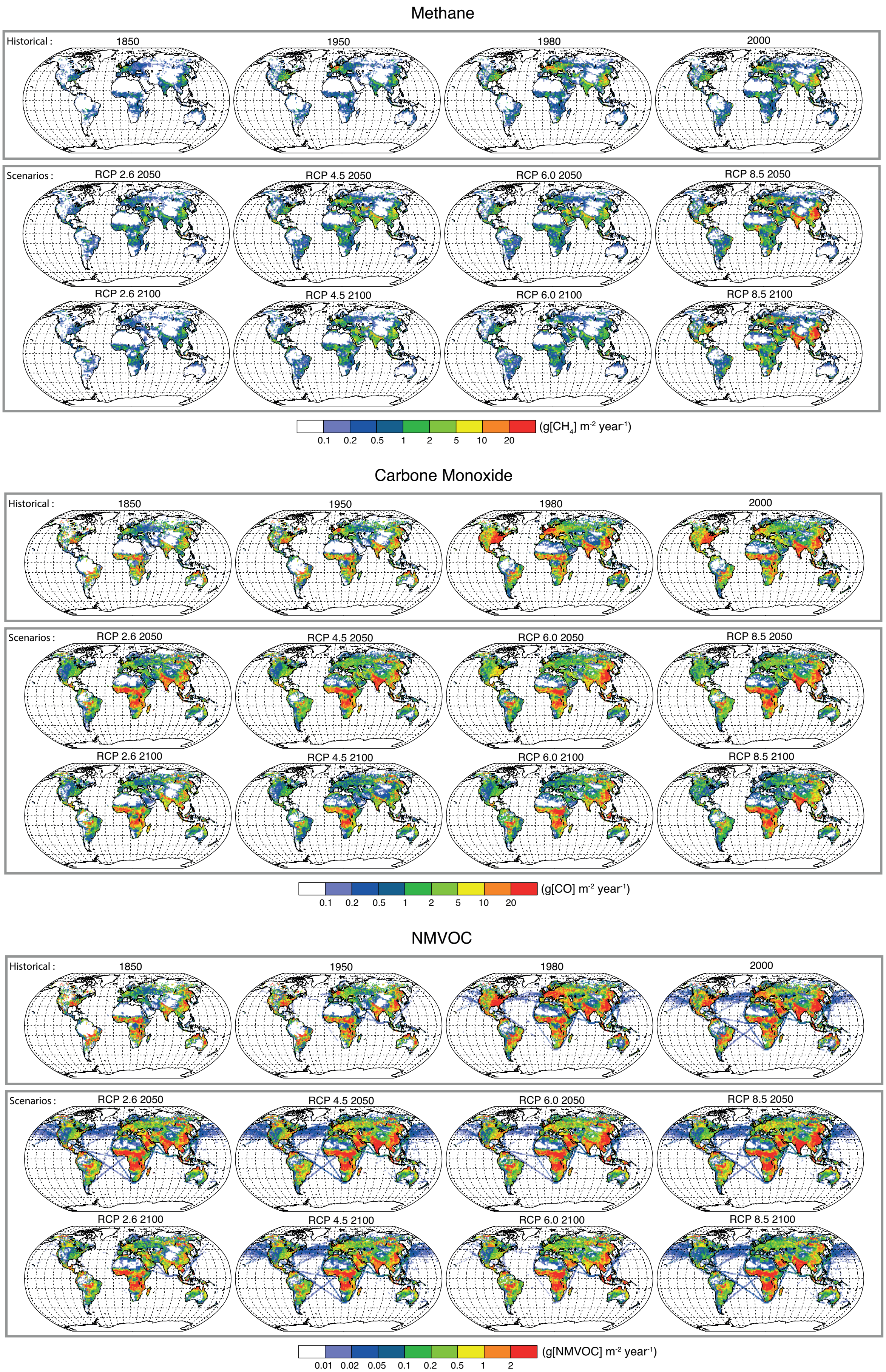

Figure 8.SM.2 | Time evolution of anthropogenic and biomass burning emissions 1850–2100 used in CMIP5/ACCMIP following each RCP. Historical (1850–2000) values are from Lamarque et al. (2010). RCP values are from van Vuuren et al. (2011).

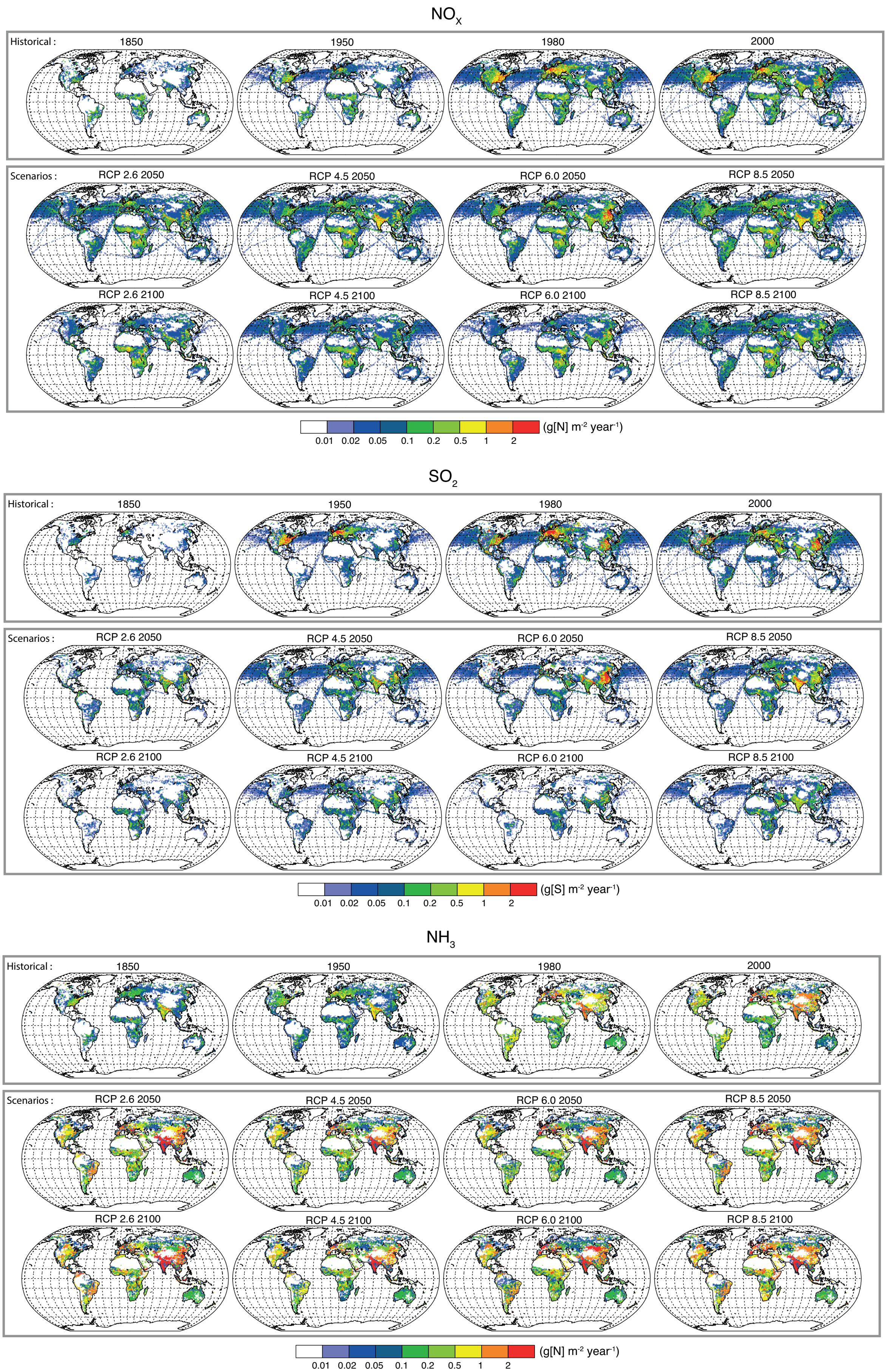

Figure 8.SM.2 | (continued)

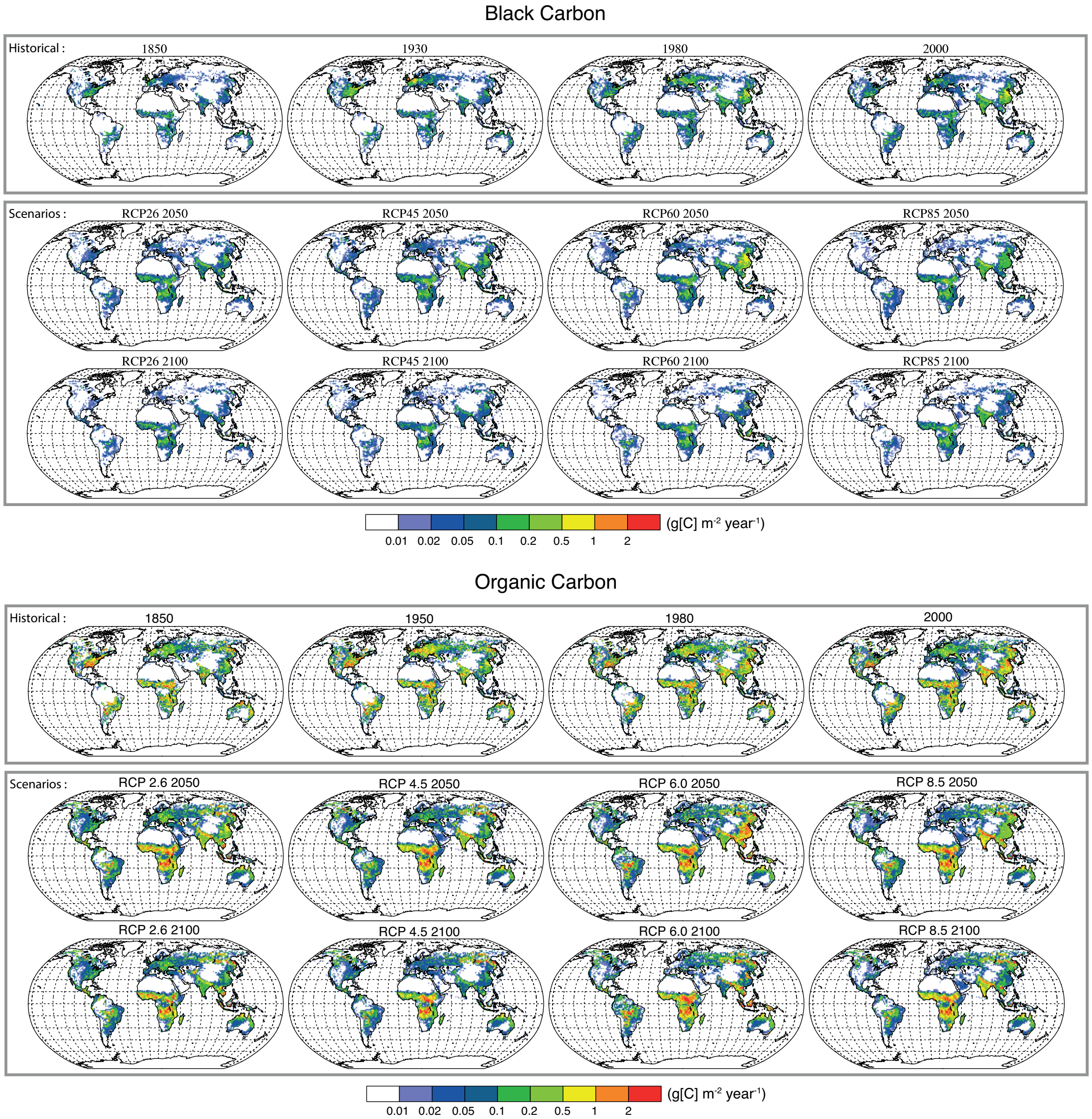

Figure 8.SM.2 | (continued)

8.SM.2 Description of Hydroxyl Radical Feedback and Perturbation Lifetime for Methane to Support Section 8.2.3

The methane lifetime with respect to tropospheric hydroxyl radical (OH) is estimated at 11.2 ± 1.3 years, while the lifetime of methane (CH_4) with respect to additional sinks is estimated at 120 ± 24 years (bacterial uptake in soils), 150 ± 50 years (stratospheric loss) and 200 ± 100 years (chlorine loss), respectively. This leads to a total CH_4 lifetime estimate of 9.25 ± 0.6 years, calculated by computing the total lifetime using the full range of each separate lifetime listed above. Note that adding the inverse values of the best estimates of the lifetimes gives 9.15 years, but the value based on full ranges is chosen here. Combining this information with the OH-lifetime sensitivity (s) for CH_4, s_OH (0.31 ± 0.04) by scaling s_OH with the ratio between total lifetime and OH-lifetime (9.25/11.2) leads to an overall estimate of s of 0.25 ± 0.03 and therefore gives a feedback factor $f = 1/(1 - s) = 1.34 \pm 0.06$ (for 1-σ range). The error estimate on f is estimated from the error estimate on s using error(f) = error(s) * df/ds.

The perturbation lifetime is therefore calculated by combining the range of values for the CH_4 lifetime with the range of values for the feedback factor, leading to a perturbation lifetime of 12.4 ± 1.4 years (for one sigma range) which is adopted for the metric calculations. Note that this value is slightly larger than the value obtained using the mean estimates from all parameters (12.3 years).

8.SM.3 Well-Mixed Greenhouse Gas Radiative Forcing Formulae and Uncertainties to Support Table 8.3

The formulae used to calculate the radiative forcings (RFs) from carbon dioxide (CO_2), CH_4 and nitrous oxide (N_2O) are taken from Myhre et al. (1998) Table 3 as in Third Assessment Report (TAR) and Fourth Assessment Report (AR4). They are listed here for convenience.

In calculating the uncertainties in the WMGHG RF we assume a ±10% (5 to 95% confidence interval) uncertainty in the radiative transfer modeling that is correlated across all species. We assume the uncertainties in the measurements of the 1750 and 2011 abundance levels of the gases are uncorrelated.

Table 8.SM.1 | Supplementary for Table 8.3: RF formulae for CO_2, CH_4 and N_2O.

Gas	RF (in W m^{-2})	Constant α
CO_2	$\Delta F = \alpha \ln(C/C_0)$	5.35
CH_4	$\Delta F = \alpha\left(\sqrt{M}-\sqrt{M_0}\right)-\left(f(M,N_0)-f(M_0,N_0)\right)$	0.036
N_2O	$\Delta F = \alpha\left(\sqrt{N}-\sqrt{N_0}\right)-\left(f(M_0,N)-f(M_0,N_0)\right)$	0.12

Notes:

f (M , N) = 0.47 ln [1+2.01×10^{-5} (MN)0.75 + 5.31×10^{-15} M $(MN)^{1.52}$]

C is CO_2 in ppm.

M is CH_4 in ppb.

N is N_2O in ppb.

The subscript 0 denotes the unperturbed molar fraction for the species being evaluated. However, note that for the CH_4 forcing N_0 should refer to present-day N_2O, and for the N_2O forcing M_0 should refer to present-day CH_4.

Table 8.SM.2 | Supplementary for Table 8.3: Uncertainties in WMGHG RF.

	CO_2	CH_4	N_2O	Halogens	Total WMGHG
Uncertainty in 1750 level	2 ppm	25 ppb	7 ppb	0	
Uncertainty in 2011 level	0.16 ppm	2.5 ppb	0.1 ppb	0	
dRF 1750 level (W m^{-2})	0.039	0.01	0.023	0	0.047
dRF 2011 level (W m^{-2})	0.003	0.00	0.000	0	0.003
dRF radiative transfer modeling (W m^{-2})	0.182	0.05	0.017	0.036	0.283
Total uncertainty (W m^{-2})	0.186	0.05	0.029	0.036	0.287

8.SM.4 Total Solar Irradiance Reconstructions from 1750 to 2012 to Support Section 8.4.1

Table 8.SM.3 | Total Solar Irradiance (TSI, W m^{-2}) reconstruction since 1750 based on Ball et al. (2012) and Krivova et al.(2010) (annual resolution series). The series are standardized to the Physikalisch-Meteorologisches Observatorium Davos (PMOD) measurements of solar cycle 23 (1996–2008) (PMOD is already standardized to Total Irradiance Monitor (TIM)).

Year	TSI (W m^{-2})	Year	TSI (W m^{-2})	Year	TSI (W m^{-2})
1740	1360.71	1841	1361.05	1942	1361.22
1741	1360.73	1842	1360.96	1943	1360.96
1742	1360.79	1843	1360.90	1944	1360.93
1743	1360.59	1844	1360.83	1945	1361.14
1744	1360.52	1845	1360.81	1946	1361.18
1745	1360.49	1846	1360.83	1947	1361.68
1746	1360.49	1847	1360.55	1948	1362.07
1747	1360.47	1848	1360.87	1949	1361.90
1748	1360.70	1849	1361.32	1950	1361.80
1749	1360.98	1850	1361.18	1951	1361.27
1750	1361.00	1851	1361.12	1952	1361.33
1751	1360.90	1852	1361.15	1953	1361.18
1752	1360.79	1853	1361.08	1954	1361.02
1753	1360.76	1854	1360.93	1955	1361.12
1754	1360.69	1855	1360.80	1956	1361.47

(continued on next page)

Table 8.SM.3 (continued)

Year	TSI (W m^{-2})	Year	TSI (W m^{-2})	Year	TSI (W m^{-2})
1755	1360.61	1856	1360.73	1957	1361.95
1756	1360.60	1857	1360.73	1958	1362.43
1757	1360.65	1858	1360.86	1959	1362.17
1758	1360.64	1859	1360.95	1960	1362.11
1759	1360.26	1860	1361.22	1961	1361.81
1760	1360.19	1861	1361.26	1962	1361.37
1761	1360.89	1862	1361.10	1963	1361.28
1762	1360.95	1863	1361.04	1964	1361.14
1763	1360.87	1864	1360.88	1965	1361.06
1764	1360.84	1865	1360.87	1966	1361.09
1765	1360.61	1866	1360.85	1967	1361.40
1766	1360.65	1867	1360.73	1968	1361.63
1767	1360.74	1868	1360.72	1969	1361.57
1768	1361.12	1869	1360.96	1970	1361.68
1769	1361.37	1870	1360.80	1971	1361.60
1770	1361.59	1871	1361.19	1972	1361.56
1771	1361.41	1872	1361.09	1973	1361.32
1772	1361.38	1873	1361.11	1974	1361.17
1773	1361.12	1874	1361.00	1975	1361.05
1774	1360.99	1875	1360.89	1976	1360.98
1775	1360.72	1876	1360.79	1977	1361.29
1776	1360.67	1877	1360.76	1978	1361.95
1777	1360.74	1878	1360.70	1979	1362.23
1778	1361.12	1879	1360.68	1980	1362.10
1779	1360.75	1880	1360.71	1981	1362.08
1780	1360.50	1881	1360.95	1982	1361.69
1781	1360.58	1882	1360.86	1983	1361.67
1782	1360.80	1883	1360.78	1984	1361.12
1783	1360.52	1884	1361.13	1985	1361.09
1784	1360.57	1885	1361.02	1986	1361.09
1785	1360.66	1886	1360.90	1987	1361.11
1786	1360.84	1887	1360.76	1988	1361.70
1787	1361.00	1888	1360.73	1989	1362.11
1788	1361.25	1889	1360.70	1990	1361.86
1789	1360.76	1890	1360.70	1991	1361.93
1790	1360.58	1891	1360.86	1992	1362.00
1791	1360.59	1892	1361.03	1993	1361.46
1792	1360.63	1893	1361.26	1994	1361.20
1793	1360.53	1894	1361.53	1995	1361.15
1794	1360.53	1895	1361.38	1996	1361.02
1795	1360.80	1896	1361.17	1997	1361.12
1796	1360.76	1897	1360.98	1998	1361.46
1797	1360.69	1898	1360.91	1999	1361.76
1798	1360.68	1899	1360.88	2000	1361.93

(continued on next page)

Table 8.SM.3 (continued)

Year	TSI (W m^{-2})	Year	TSI (W m^{-2})	Year	TSI (W m^{-2})
1799	1360.66	1900	1360.80	2001	1361.84
1800	1360.60	1901	1360.69	2002	1361.79
1801	1360.85	1902	1360.65	2003	1361.31
1802	1360.93	1903	1360.74	2004	1361.09
1803	1360.76	1904	1361.08	2005	1360.92
1804	1360.71	1905	1360.89	2006	1360.88
1805	1360.67	1906	1361.21	2007	1360.88
1806	1360.74	1907	1361.00	2008	1360.82
1807	1360.58	1908	1361.15	2009	1360.81
1808	1360.53	1909	1360.99	2010	1361.01
1809	1360.53	1910	1360.96	2011	1361.22
1810	1360.49	1911	1360.77	2012	1361.42
1811	1360.48	1912	1360.67		
1812	1360.48	1913	1360.70		
1813	1360.50	1914	1360.76		
1814	1360.53	1915	1361.10		
1815	1360.55	1916	1361.50		
1816	1360.62	1917	1361.63		
1817	1360.65	1918	1361.89		
1818	1360.61	1919	1361.53		
1819	1360.60	1920	1361.29		
1820	1360.57	1921	1361.09		
1821	1360.53	1922	1360.90		
1822	1360.52	1923	1360.82		
1823	1360.50	1924	1360.79		
1824	1360.57	1925	1360.89		
1825	1360.62	1926	1361.15		
1826	1360.68	1927	1361.47		
1827	1360.87	1928	1361.24		
1828	1360.95	1929	1361.21		
1829	1360.96	1930	1361.35		
1830	1361.01	1931	1361.07		
1831	1361.01	1932	1360.89		
1832	1360.86	1933	1360.79		
1833	1360.75	1934	1360.80		
1834	1360.72	1935	1360.95		
1835	1360.76	1936	1361.50		
1836	1361.13	1937	1361.65		
1837	1361.40	1938	1361.59		
1838	1361.38	1939	1361.69		
1839	1361.21	1940	1361.51		
1840	1361.20	1941	1361.42		

8.SM.5 Table with Estimates of Radiative Forcing due to Solar Changes over the Industrial Era to Support Section 8.4.1

Table 8.SM.4 | Comparison of RF estimates between 1745 and 2008 minima.

Reference	Assumptions	RF (W m^{-2})	Comments
Wang et al. (2005)	Use a flux transport model to simulate the evolution of total and open magnetic flux without a secularly varying background	0.019 (7-year rm) 0.013 (annual)	
Wang et al. (2005)	Same as above but with a secularly varying background	0.071 (7-year rm) 0.065 (annual)	Used to estimate RF in AR4
Steinhilber et al. (2009)	Use the solar modulation potential obtained from cosmogenic isotopes	-0.02 (5-years resolutions)	
Krivova et al. (2010) Ball et al. (2012)	Use the evolution of the solar surface magnetic field, relying on time constants representing the decay and conversion of different surfaces magnetic field structures	0.048 (7-year rm) 0.045 (annual)	

Notes:

rm = running means. For the reconstructions based on solar surface magnetic structures, with annual resolution, the year of the minimum is 1745. However, for the Steinhilber et al. (2009) reconstruction, based on cosmogenic isotopes, the minimum is in 1765, because the resolution of the series is 5 years.

8.SM.6 Further Information on Total Solar Irradiance, Uncertainties and Change Since the Maunder Minimum to Support Section 8.4.1

The absolute measurements of TSI are extremely difficult with an absolute accuracy better than 0.1%. All TSI instruments since 1979 have been calibrated, relatively or absolutely. In order to maintain a reasonable accuracy in the annual to multi-decadal timeframe it is essential to have at least three independent sensors operating in space simultaneously. The fundamental difficulties of the absolute measurements are described in Butler et al. (2008). Fox et al. (2011) quantified how the uncertainty in satellite TSI measurements could be improved by an order of magnitude by adding primary SI traceability on board. For instance, to reduce from 3.60% for Moderate Resolution Imaging Spectrometer (MODIS)/Visible Infrared Imaging Radiometer Suite (VIIRS) to 0.30% for Traceable Radiometry Underpinning Terrestrial- and Helio-Studies (TRUTHS). This would reduce by 67 to 75% the time required to achieve trend accuracy.

The Spectral Irradiance Monitor (SIM) on board of the Solar Radiation and Climate Experiment (SORCE) measurements (Harder et al., 2009) suggest that over solar cycle (SC) 23 declining phase, the 200 to 400 nm ultraviolet (UV) flux decreased by two to six times more than expected from prior observations and model calculations and in phase with the TSI trend, whereas surprisingly the visible presents an opposite trend. However, SIM's solar spectral irradiance measurements from April 2004 to December 2008 and inferences of their climatic implications are incompatible with the historical solar UV irradiance database, coincident solar proxy data, current understanding of the sources of solar irradiance changes and empirical climate change attribution results, but are consistent with known effects of instrument sensitivity drifts. Thus what seems to be needed is improved characterization of the SIM/SORCE observations and extreme caution in studies of climate and atmospheric change (Haigh et al., 2010) until additional validation and uncertainty estimates are available (DeLand and Cebula, 2012; Lean and Deland, 2012).

8.SM.6.1 Uncertainties

1. PMOD RF and uncertainty between 1986 and 2008:
According to PMOD, 2009 is the year of the TSI minimum, but according to TIM it is 2008. We take the year 2008 as the year of the minimum.

The PMOD TSI mean for September 2008 was 1365.26 ± 0.16 W m^{-2}, whereas in the 1986 minimum it was 1365.57 ± 0.01 W m^{-2} (Frohlich, 2009).

Difference between 2008 and 1986 minima:
1365.26 ± 0.16 – 1365.57 ± 0.01

Applying the error propagation formula:
$(a \pm x) - (b \pm y) = (a - b) \pm [x^2 + y^2)]^{1/2}$

That for our case is:
$(1365.26 - 1365.57) \pm [(0.16)^2 + (0.01)^2]^{1/2} = -0.31 \pm 0.16$

The RF is:
$[-0.31 \pm 0.16] * 0.175 * 0.78 = -0.042 \pm 0.022 \sim -0.04 \pm 0.02$ W m^{-2}

8.SM.6.2 Standardization

We use the following expression to standardize the time series:
$[S_i - <S>] + <S^*>$

Where S_i is the annual TSI of the series that will be standardized.

$<S>$ is the TSI average of the whole time span of series that will be standardized.

$<S^*>$ is the TSI average of the series we are using as the standard. In our case the TIM TSI between 2003 and 2012 or the PMOD TSI for SC 23 (1996–2008).

For the RF estimates the years with minimum solar activity based on modern or historical observations are used as provided in the referenced literature. These years may in some cases be slightly different from the years with minimum annual mean TSI (see Table 8.SM.3), but these differences have a negligible impact on the RF estimates provided in Section 8.4.1.

8.SM.6.3 Total Solar Irradiance Variations Since the Maunder Minimum

For the Maunder minimum (MM)-to-present AR4 gives a RF positive range of 0.1 to 0.28 W m^{-2}, equivalent to 0.08 to 0.22 W m^{-2} used here. The estimates based on irradiance changes in Sun-like stars were included in this range but are not included in the Fifth Assessment Report (AR5) range because they are now considered incorrect: Baliunas and Jastrow (1990) found a bimodal separation between noncycling MM-like state stars with the lowest Ca II brightness, and the higher emission Ca II cycling stars. More recent surveys have not reproduced their results and suggest that the selection of the original set was flawed (Wright (2004); also, stars in a MM-like state do not always exhibit Ca II emission brightness below that of solar minimum (Hall and Lockwood (2004).

The reconstructions in Schmidt et al. (2011) indicate a MM-to-present RF range of 0.08 to 0.18 W m^{-2}, which is within the AR4 range although narrower. Gray et al. (2010) point out that choosing the solar activity minima years of 1700 (Maunder) or 1800 (Dalton) would substantially increase the solar RF with respect to 1750-to-present while leaving the anthropogenic forcings essentially unchanged, and that these solar minima forcings would represent better the solar RF of the pre-industrial era.

Other recent estimates give various MM-to-present RF values: The analysis of Shapiro et al. (2011) falls outside the range 0.08 to 0.18 W m^{-2} reported above: 0.78 W m^{-2}. These authors used the semi-empirical photosphere model A (supergranule cell interior) of Fontenla et al. (1999). But Judge et al. (2012) indicate that by using such model Shapiro et al. (2011) overestimated the quiet-Sun irradiance variations by a factor of about two, then the RF would be 0.36 W m^{-2} , which is still outside the range of Schmidt et al. (2011). Studies of magnetic field indicators suggest that changes over the 19th and 20th centuries were more modest than those assumed in the Shapiro et al. (2011) reconstruction (Svalgaard and Cliver, 2010; Lockwood and Owens, 2011). Also, analysis by Feulner (2011) indicates that temperature simulations driven by such a large solar forcing are inconsistent with reconstructed and observed historical temperatures, although when a forcing in line with the range presented here is used they are consistent. Hence we do not include this larger forcing within our assessed range. Schrijver et al. (2011) and Foukal et al. (2011) find a RF which is consistent with the RF range given above (0.08 to 0.18 W m^{-2}).

Almost all the TSI reconstructions since pre-industrial times are based on the Sunspot Group Number (SGN; Hoyt and Schatten (1998). The SGN is preferred by researchers respect to the International Sunspot Number (Clette et al., 2007) because SGN starts at 1610 and it is the longest time series based on direct solar observations.

As these two sunspot number versions are quite different in the historical period, using one or the other results in different trends since the MM (Hathaway et al., 2002) and therefore different RF estimates. Moreover, Svalgaard et al. (2012) have published some preliminary corrections to SGN that could imply a reduction in the RF since the MM.

8.SM.7 Method Description to Support Figure 8.16

In Figure 8.16, probability distributions are shown for the main climate drivers as well as for the total anthropogenic forcing. This paragraph describes how it was built.

For each of the major forcing agents, a best estimate and a 90% uncertainty range [P05; P95] was provided. The *best estimate* is the median of the probability distribution. The values are available in Table 8.6 and repeated below. For some forcing agents, the best estimate and the uncertainty range are provided for RF, and not for effective radiative forcing (ERF). In such a case, we assume that $ERF_{Best}=RF_{Best}$ and we assumed a quadratic 17% increase of the uncertainty range σ, that is:

$$\sigma_{ERF}^2 = \sigma_{RF}^2 + \left(0.17\, RF_{Best}\right)^2 \qquad (8.SM.1)$$

Most forcing agents considered here (WMGHG, ozone, stratospheric H_2O, land use change) have symmetrical uncertainty ranges (i.e., Best = (P05 + P95)/2). For these forcing agents, the probability distribution is assumed to be Gaussian, with a standard deviation as

$$\sigma = \frac{P95 - P05}{2f} \qquad (8.SM.2)$$

where $f \approx 1.645$ is the factor to convert one standard deviation to the 5-95% probability range.

The other forcing agents (black carbon on snow, contrails, aerosols) have non-symmetrical uncertainty ranges. For black carbon and snow, we assume a log-normal distribution as

$$P(x) = \frac{1}{x\,\sigma\sqrt{2\pi}} \exp\left(-\frac{\ln^2(x/x_0)}{2\sigma^2}\right) \qquad (8.SM.3)$$

with x_0 as the best estimate and σ adjusted to fit P05 and P50 (σ_{BC} = 0.5 ; $\sigma_{Contrails}$ = 0.65).

For the aerosols, which have a non-symmetrical uncertainty range, we build a probability distribution as

$$P(x) = \frac{1}{\sqrt{2\pi}} \frac{2}{\sigma_+ + \sigma_-} \exp\left(-\frac{(x-x_0)^2}{2\sigma^2}\right)$$
$$x \le x_0 \quad \sigma = \sigma_-$$
$$x \ge x_0 \quad \sigma = \sigma_+ \qquad (8.SM.4)$$

x_0, σ_- and σ_+ are adjusted to fit the best estimates and 90% uncertainty ranges:

$$x_0 \approx \frac{\frac{4}{5}\sqrt{\frac{2}{\pi}}(P05+P95)-(2\alpha+f)Best}{\frac{8}{5}\sqrt{\frac{2}{\pi}}-(2\alpha+f)}$$

$$\sigma_+ = \frac{(\alpha+f)(P95-x_0)+\alpha(x_0-P05)}{(\alpha+f)^2-\alpha^2}$$

and

$$\sigma_- = \frac{(\alpha+f)(x_0-P05)+\alpha(P95-x_0)}{(\alpha+f)^2-\alpha^2}$$

with

$$\alpha = 0.05\sqrt{\frac{\pi}{2}}\exp\left(\frac{f^2}{2}\right)\approx 0.2425 \quad (8.SM.5)$$

The total anthropogenic ERF distribution was then derived through a Monte Carlo approach (10^6 independent shots), summing the random estimates of all components. This approach assumes that all forcing agent uncertainties are independent. The results are provided in Table 8.SM.5.

Table 8.SM.5 | Best estimate values and 5 and 95% ranges for RF and ERF. Yellow are the input values, green the extrapolated values (from RF to ERF) and red is the result of the Monte Carlo addition.

	RF			ERF		
Forcing agent	**Best**	**P05**	**P95**	**Best**	**P05**	**P95**
Well-mixed greenhouse gases				2.83	2.26	3.40
Ozone	0.350	0.15	0.55	0.350	0.141	0.559
Stratospheric H_2O	0.070	0.02	0.12	0.070	0.019	0.121
Surface albedo	–0.15	–0.25	–0.05	–0.150	–0.253	–0.047
Black carbon on snow	0.04	0.02	0.08	0.040	0.019	0.090
Contrails				0.05	0.02	0.15
Aerosols				–0.90	–1.90	–0.10
Total				2.29	1.13	3.33

8.SM.8 Table with Values and Uncertainties to Support Figure 8.17

Table 8.SM.6 | Radiative forcing (RF, in W m^{-2}) by emitted components as shown in Figure 8.17. The RF values are made consistent with Table 8.6. For emissions of CO_2, CH_4, CO, NMVOCs and NO_x the values for the influence on CO_2, CH_4 and ozone are based on Stevenson et al. (2013) and Shindell et al. (2009). The seven models altogether performing the calculations for these compounds (six models in Stevenson et al., (2013); and one model in Shindell et al., (2009) have been treated with equal weight. For CO, CH_4 and NMVOC only fossil fuel emissions have been taken into account. The split between NO_x and NH_3 of 40/60 on the RF of nitrate is from Shindell et al. (2009). The BC and OC from biomass burning is set to +0.2 and –0.2, respectively and thus a net RF of biomass burning of 0.0, in line with Table 8.4. BC ari is RF of BC from aerosol–radiation interaction, formerly denoted as direct aerosol effect. Unlike in AR4 (Table 2.13) the N_2O influence on RF of ozone has been set to zero, due to insufficient quantification of this and particularly the vertical profile of the ozone change. ERFaci is effective radiative forcing of aerosol–cloud interaction.

	CO_2	CH_4	N_2O	CFCs/ HCFCs	HFCs/ PFCs/ SF_6	BC ari	BC snow & ice	OC	Ozone	H_2O(Str)	Nitrate	Sul-phate	ERFaci	Total
Components emitted														
CO_2	1.68													**1.680**
CH_4	0.018	0.641							0.241	0.07				**0.970**
N_2O			0.17						0					**0.170**
CFCs/HCFCs/ halons				0.33					–0.15					**0.180**
HFCs/PFCs/SF_6					0.03									**0.030**
CO	0.087	0.072							0.075					**0.234**
NMVOC	0.033	0.025							0.042					**0.100**
NO_x		–0.254							0.143		–0.04			**–0.151**
NH_3											–0.07	0.01		**–0.060**
BC						0.60	0.04							**0.640**
OC								–0.29						**–0.290**
SO_2												–0.41		**–0.410**
Aerosols													–0.45	**–0.450**
SUM	**1.82**	**0.48**	**0.17**	**0.33**	**0.03**	**0.60**	**0.04**	**–0.29**	**0.35**	**0.07**	**–0.11**	**–0.40**	**–0.45**	

Table 8.SM.7 | Percentage uncertainty in values provided in Table 8.SM.6.

	Uncertainty (%)	Source
Components emitted		
CO_2	10	10% uncertainty in the total RF of CO_2 and combined with assumed 50% uncertainty for other contributions
CH_4	17	14% uncertainty in CH_4 contribution from Section 8.3.3, 55% uncertainty for contribution to ozone, 71% for stratospheric water vapour and 50% assumed for contribution to CO_2
N_2O	17	
CFCs/HCFCs/halons	85	10% uncertainty for direct effect and 100% for change in stratospheric ozone (see Section 8.3.3)
HFCs/PFCs/SF_6	10	
CO	24	30% uncertainty in CH_4 contribution Section 8.3.3, 37% for ozone contribution (Section 8.3.3) assumed 50% for contribution to CO_2
NMVOC	41	100% uncertainty in CH_4 contribution Section 8.3.3, 70% for ozone contribution and assumed 50% for contribution to CO_2
NO_x	(–124 to +116)	58% uncertainty in CH_4 contribution Section 8.3.3, 64% for ozone contribution and the range for nitrate as provided in Table 8.4
NH_3	(–172 to +73)	Same uncertainty as nitrate in Table 8.4
BC	(–61 to +70)	See Table 8.4 and Table 8.6 for BC from fossil fuel and biofuel and BC on snow and ice, respectively. BC from biomass burning is given as +0.2 (0.03 to 0.4); see Section 7.5.1.2
OC	(–63 to +72)	See Table 8.4 for OC from fossil fuel and biofuel. OC from biomass burning is given as –0.2 (–0.4 to –0.03); see Section 7.5.1.2
SO_2	50	See Table 8.4
ERFaci	(–167 to +100)	ERFaci –0.45 (–1.2 to 0.0); see Table 8.6

8.SM.9 Description of Forcing Time Series to Support Figure 8.18

Table 8.SM.8 | Supplementary for Figure 8.18: Time evolution forcing.

Forcing Agent	Data Sources for Time Evolution
WMGHG	WMGHG concentration as in Annex II. RF calculated based on formulas described in Section 8.3.2. Radiative efficiencies for halocarbons are given in Table 8.A.1.
Tropospheric ozone	Values for 1850, 1930, 1980 and 2000 from Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP; Stevenson et al., 2013) and combined with higher temporal resolution from Oslo Chemical Transport Model 2 (Oslo CTM2; Skeie et al., 2011a).
Stratospheric ozone	The stratospheric ozone RF follows the functional shape of the Effective Equivalent Stratospheric Chlorine assuming a 3 years age of air (Daniel et al., 2010).
Stratospheric water vapour	RF is 15% of the CH_4 RF.
Total aerosol ERF	Values for 1850, 1930, 1980 and 2000 from ACCMIP (Shindell et al., 2013) combined with higher temporal results from Spectral Radiation-Transport Model for Aerosol Species (SPRINTARS) and Oslo CTM2 for the Industrial Era and Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Geophysical Fluid Dynamics Laboratory (GFDL) models in addition for the 2000–2010 period. All four models included in Shindell et al. (2013). Note that Oslo CTM2 and CSIRO do not include rapid adjustment for the aerosol–cloud interaction.
Aerosol–radiation interaction	Values for 1850, 1930, 1980 and 2000 from ACCMIP (Shindell et al., 2013) combined with higher temporal results from Goddard Institute for Space Studies (GISS) and Oslo CTM2 models.
Surface albedo (land use change)	Based on an assessment of the time series from Skeie et al. (2011a), Hansen et al. (2011), Pongratz et al. (2009) and Schmidt et al. (2012). Time series scaled to fit the best estimate for 2011.
Surface albedo (BC on snow)	Values for 1850, 1930, 1980 and 2000 from ACCMIP (Lee et al., 2013) combined with higher temporal results from Oslo CTM2 (Skeie et al., 2011b).
Contrails	The best estimate for contrails (RF) or combined contrails and contrail induced cirrus (ERF) is scaled to aircraft kilometres flown in table downloaded from the following website: http://www.airlines.org/Pages/Annual-Results-World-Airlines.aspx.
Solar	TSI reconstructions (Krivova et al., 2010; Ball et al., 2012) standardized to Physikalisch-Meteorologisches Observatorium Davos (PMOD) and Total Irradiance Monitor (TIM) data is divided by 4 and multiplied by the Earth co-albedo (1 – 0.3) and multiplied with 0.78 to account for absorption in the stratosphere (see Section 8.4.1). TSI provided in the Supplementary Material Table 8.SM.3.
Volcanic aerosols	Mean of (Gao et al., 2008; Crowley and Unterman, 2013) between 1750 and 1850 and (Sato et al., 1993; updated version of April, 2013) from 1850 to present. RF is calculated as RF = AOD * (–25.0) W m^{-2}.

8.SM.10 Uncertainties in Trends in Forcing to Support Figure 8.19

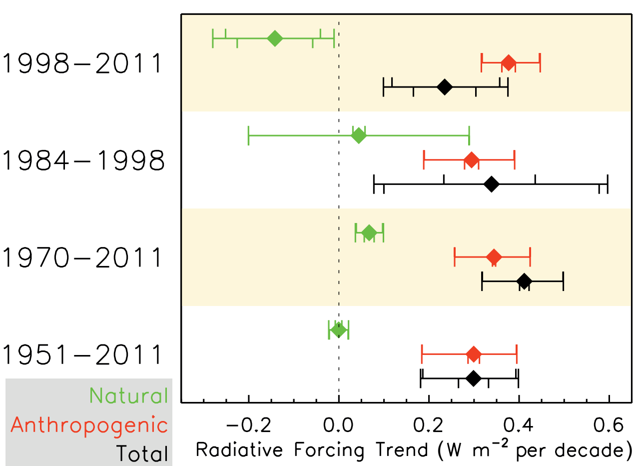

Figure 8.SM.3 | Linear trend in anthropogenic, natural and total forcing for the indicated years. The uncertainty ranges (90% confidence range) are combined from uncertainties in the forcing values (from Table 8.6) (upward vertical lines) and the uncertainties in selection of time period (downward vertical lines). Monte Carlo simulations were performed to derive uncertainties in the forcing based on ranges given in Table 8.6 and linear trends in forcing. The sensitivity to time periods has been derived from changing the time periods by ±2 years.

8.SM.11 Definition and Methods to Calculate Metric Values to Support Section 8.7.1

8.SM.11.1 Equations for the Global Warming Potential

The Absolute Global Warming Potential (AGWP) is the time-integrated radiative forcing due to a 1 kg *pulse* emission of gas *i* (usually in W m^{-2} yr kg^{-1}). The Global Warming Potential (GWP) for gas *i* is obtained by dividing the $AGWP_i$ by the AGWP of a reference gas, normally CO_2:

$$GWP_i(H) = \frac{AGWP_i(H)}{AGWP_{CO_2}(H)} = \frac{\int_0^H RF_i(t)dt}{\int_0^H RF_{CO_2}(t)dt} \qquad (8.SM.6)$$

where *H* is the time horizon; RF_i is the radiative forcing due to a *pulse* emission of a gas *i* given by

$$RF_i = A_i R_i \qquad (8.SM.7)$$

where A_i is the RF_i per unit mass increase in atmospheric abundance of species *i* (radiative efficiency (RE)), and R_i is the fraction of species *i* remaining in the atmosphere after the pulse emissions. The GWP are currently not defined using the Effective Radiative Forcing (ERF, Section 8.1.1.2), but this could be considered as a potential improvement of the concept.

For most species, R_i is based on a simple exponential decay,

$$R_i(t) = \exp\left(-\frac{t}{\tau_i}\right) \quad (8.SM.8)$$

where τ_i is the perturbation lifetime and thus, for these species,

$$AGWP_i(H) = \int_0^H RF_i(t)\,dt = A_i\tau\left(1-\exp\left(-\frac{H}{\tau}\right)\right) \quad (8.SM.9)$$

The atmospheric decay of a pulse consists of many different time scales (Prather, 1994). Nevertheless, for gases with atmospheric lifetimes larger than the mixing times of the major reservoirs (>3 years), the decay can be approximated as it is here with a single *e*-fold time equal to the perturbation lifetime. In this case the total integrated impacts are exact (Prather, 2007). For very short-lived gases (<1 year), the single *e*-fold also provides the correct integral, but the impacts occur over a longer time frame than expected from the perturbation lifetime.

For CO_2, R_i is more complicated because its atmospheric response time (or lifetime of a perturbation) cannot be represented by a simple exponential decay (Joos et al., 2013). The decay of a perturbation of atmospheric CO_2 following a pulse emission at time t is usually approximated by a sum of exponentials (Forster et al., 2007; Joos et al., 2013):

$$R_{CO_2}(t) = a_0 + \sum_{i=1}^{N} a_i \exp\left(-\frac{t}{\tau_i}\right) \quad (8.SM.10)$$

The $AGWP_{CO2}$ is then (Shine et al., 2005):

$$AGWP_{CO_2}(H) = A_{CO_2}\left\{a_0 H + \sum_{i=1}^{I} a_i\tau_i\left(1-\exp\left(-\frac{H}{\tau_i}\right)\right)\right\} \quad (8.SM.11)$$

8.SM.11.2 Equations for the Global Temperature Change Potential

The Absolute Global Temperature change Potential (AGTP) can be represented as (Boucher and Reddy, 2008; Fuglestvedt et al., 2010):

$$AGTP_i(H) = \int_0^H RF_i(t)\,R_T(H-t)\,dt \quad (8.SM.12)$$

where R_T is the climate response to a unit forcing and can be represented as a sum of exponentials,

$$R_T(t) = \sum_{j=1}^{M} \frac{c_j}{d_j}\exp\left(-\frac{t}{d_j}\right) \quad (8.SM.13)$$

where the parameters c_j are the components of the climate sensitivity and d_j are response times. The first term in the summation can crudely be associated with the response of the ocean mixed layer to a forcing and the higher order terms the response of the deep ocean (Li and Jarvis, 2009). The equilibrium climate sensitivity is given by the equilibrium response to a sustained unit forcing, $\lambda = \Sigma c_j$.

The simplest form of R_T is a single response term ($M = 1$) (Shine et al., 2005; Olivié et al., 2012). A better representation of the climate response, however, is two or three terms ($M = 2, 3$) (Boucher and Reddy, 2008; Li and Jarvis, 2009; Olivié et al., 2012). We use R_T from Boucher and Reddy (2008) which assumes two exponential terms and is based on the Hadley Centre Coupled Model version 3 (HadCM3) model (Table 8.SM.9). The climate sensitivity is 1.06 K (W m^{-2})$^{-1}$, equivalent to a 3.9 K equilibrium response to 2 × CO_2.

8SM

Using the equations above, the AGTP with a time horizon H for the non-CO_2 greenhouse gases:

$$AGTP_i(H) = A_i\sum_{j=1}^{2}\frac{\tau c_j}{\tau - d_j}\left(\exp\left(-\frac{H}{\tau}\right) - \exp\left(-\frac{H}{d_j}\right)\right) \quad (8.SM.14)$$

and the AGTP for CO_2 is

$$AGTP_{CO_2}(H) = A_{CO_2}\sum_{j=1}^{2}\left\{a_0 c_j\left(1-\exp\left(-\frac{H}{d_j}\right)\right) + \sum_{i=1}^{3}\frac{a_i\tau_i c_j}{\tau_i - d_j}\left(\exp\left(-\frac{H}{\tau_i}\right) - \exp\left(-\frac{H}{d_j}\right)\right)\right\} \quad (8.SM.15)$$

Table 8.SM.9 | Parameter values for the response to a pulse of radiative forcing used in the AGTP calculations

	1st Term	2nd Term
c_j (K(W m^{-2})$^{-1}$)	0.631	0.429
d_j (years)	8.4	409.5

8.SM.11.3 Updates of Metric Values

The metric values need updating as a result of new scientific knowledge, but also because of changes in lifetimes and REs caused by changing atmospheric background conditions (Reisinger et al., 2011). For the reference gas CO_2, changes in $AGWP_{CO2}$ and $AGTP_{CO2}$ will affect the GWP and GTP of all other gases. With increasing CO_2 levels in the atmosphere the marginal RF is reduced, while at the same time the ocean uptake is reduced and airborne fraction increased (Caldeira and Kasting, 1993). These changes are in opposite directions, but do not totally cancel, and hence lead to changes in $AGWP_{CO2}$ (Figure 8.30) and $AGTP_{CO2}$.

To convert the RE values given per ppbv values to per kg (Shine et al., 2005), they must be multiplied by $(M_A/M_i)(10^9/T_M)$ where M_A is the mean molecular weight of air (28.97 kg kmol^{-1}), M_i is the molecular weight of species i and T_M is the total mass of the atmosphere, 5.1352 × 10^{18} kg (Trenberth and Smith, 2005).

8.SM.11.3.1 Metric Values for Carbon Dioxide

The radiative forcing for CO_2 can be approximated using the expression based on radiative transfer models (Myhre et al., 1998):

$$RF = \alpha \log\left(\frac{C_0 + \Delta C}{C_0}\right) \quad (8.SM.16)$$

where $\alpha = 5.35$ W m^{-2}, C_0 is the reference concentration and ΔC is the change from the reference. The radiative efficiency is the change in RF for a change in the atmospheric abundance,

$$RE = \frac{\Delta RF}{\Delta C} = \alpha \left(\log\left(\frac{C_0 + \Delta C}{C_0}\right) \Big/ \Delta C \right) \quad (8.SM.17)$$

or if $\Delta C \rightarrow 0$ then the derivative can be used:

$$RE = \left.\frac{dRF}{d\Delta C}\right|_{\Delta C=0} = \frac{\alpha}{C_0} \quad (8.SM.18)$$

At current CO_2 levels (391 ppm) and for $\Delta C = 1$ ppm, the radiative efficiency (RE) of CO_2 is 1.37 * 10^{-05} W m^{-2} ppb^{-1}. The difference between using $\Delta C = 1$ ppm and the derivate is 0.13%. For CO_2, using a molecular weight of 44.01 kg kmol^{-1}, the A becomes 1.7517 * 10^{-15} W m^{-2} kg^{-1}.

The impulse response function (IRF) has been updated from AR4. Table 8.SM.10 shows the parameters of the IRF used in AR5 based on Joos et al. (2013) and Figure 8.SM.4 shows the IRFs from the four previous IPCC assessment reports together with the new IRF used in AR5. Table 8.SM.11 gives calculated values for integrated IRF and AGWPs for CO_2.

Table 8.SM.10 | Parameter values for the sum of exponentials (Equation 8.SM.10) describing the fraction of CO_2 remaining in the atmosphere after a pulse emission of CO_2 (Joos et al., (2013).

	1st Term	2nd Term	3rd Term	4th Term
Coefficient (unitless)	0.2173	0.2240	0.2824	0.2763
Time Scale (τ_i, years)	-	394.4	36.54	4.304

Table 8.SM.11 | Mean and uncertainty range for the time-integrated IRF and AGWP from Joos et al. (2013). The AGWP for AR5 uses the integrated IRF based on Equation 8.SM.10 and Table 8.SM.9 and a radiative efficiency for a 1 ppm change at 391 ppm.

	20-Year	100-Year
Time-integrated IRF (year)		
Mean	14.2	52.4
5–95% range	12.2–16.3	39.5–65.2
AGWP (10^{-15} W m^{-2} yr kg^{-1})		
Mean	25.2	92.5
5 to 95% range	20.7–29.6	67.9–117
AR5 AGWP (10^{-15} W m^{-2} yr kg^{-1})	24.9	91.7

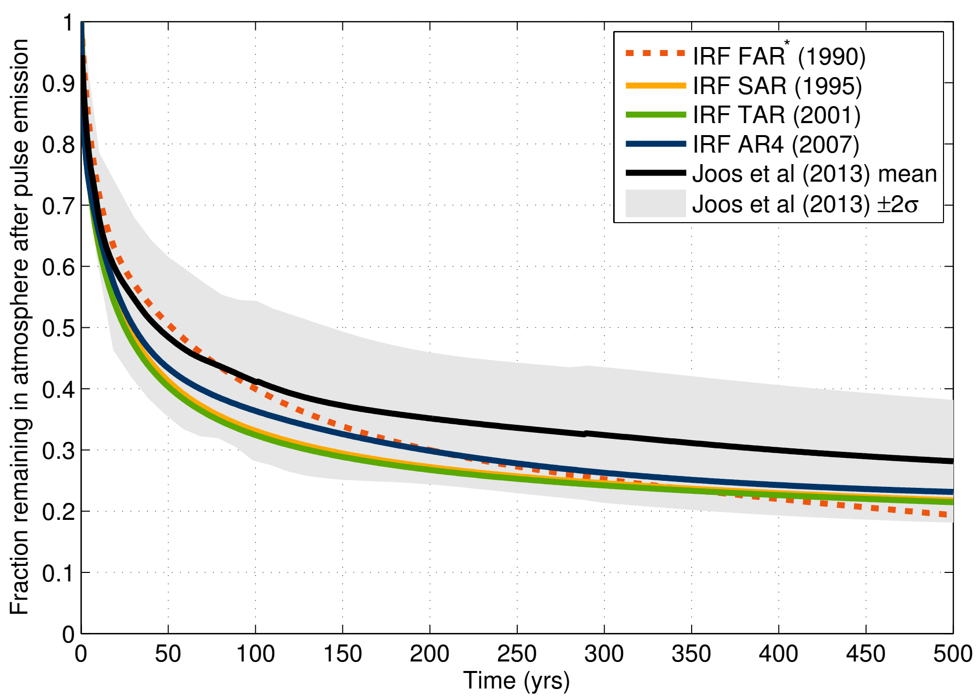

Figure 8.SM.4 | The impulse response functions (IRFs) from the five IPCC Assessment Reports. The First Assessment Report (FAR) IRF (dotted) is based on an unbalanced carbon-cycle model (ocean only) and thus is not directly comparable to the others. The Second Assessment Report (SAR) IRF is based the CO_2 response of the Bern model (Bern-SAR), an early generation reduced-form carbon cycle model (Joos et al., 1996), and uses a 10 GtC pulse emission into a constant background without temperature feedbacks (Enting et al., 1994). The IRF was not updated for the Third Assessment Report (TAR), but a different parameterisation was used in World Meterological Organisation (WMO)/United Nations Environment Programme (UNEP) Scientific Assessment of Ozone Depletion: 1998 (WMO, 1999) The Fourth Assessment Report (AR4) IRF is based on the Bern 2.5CC Earth System Model of Intermediate Complexity (EMIC) (Plattner et al., 2008). A pulse size of 40 GtC is used and includes temperature feedbacks. The Fifth Assessment Report (AR5) IRF is based on a model intercomparison and uses a pulse size of 100 GtC and includes temperature feedbacks (Joos et al., 2013). Apart from FAR, the changing IRF in each assessment report represents increasing background concentrations and improved models.

8.SM.11.3.2 Metric Values for Methane

The RE of CH_4 is scaled to include effects on ozone and stratospheric H_2O, so that the AGWP becomes

$$AGWP_{CH_4}(H) = (1+f_1+f_2)A_{CH_4}\int_0^H e^{-t/\tau}dt = (1+f_1+f_2)A_{CH_4}\tau(1-e^{-H/\tau}) \quad (8.SM.19)$$

where f_1 is due to effects on ozone and f_2 is due to stratospheric H_2O. The AGTP is modified in a similar way.

These indirect effects were included in AR4 by increasing the direct RF from CH_4 by 25% (due to tropospheric ozone) and 15% (due to stratospheric H_2O). New studies provide updated values and include more effects. By accounting for aerosol responses, Shindell et al. (2009) found that the GWP for CH_4 increased by about 40% while Collins et al. (2010) found that the GTP for CH_4 increased by 5 to 30% when the effect of ozone on CO_2 was included. Boucher et al. (2009) included the effect of CO_2 from oxidation of CH_4 from fossil sources and calculated a GWP_{100} higher than given in AR4 (27 to 28 versus 25). They found that CO_2 oxidation had a larger effect on GTP values and this effect was larger than the direct CH_4 effect for time horizons beyond 100 years.

In AR5 we use updated estimates for the indirect effects of CH_4 on ozone based on recent studies (Shindell et al., 2005; Shindell et al., 2009; Collins et al., 2013; Holmes et al., 2013; Stevenson et al., 2013). Based on these studies we assess the indirect effect on ozone (tropospheric and stratospheric) to $f_1 = 0.5$ (0.2 to 0.8) of the direct effect. The indirect RF from CH_4 via changes in stratospheric H_2O is retained as $f_2 = 0.15$ of the direct effect. Thus, we increase the direct effect of CH_4 by $f_1 + f_2 = 0.65$ to account for RF from both O_3 and stratospheric H_2O. We also present metric values for CH_4 of fossil origin (based on Boucher et al., (2009); Table 1). If these metric values are used the carbon emitted as CH_4 must not be included in the CO_2 emissions (which are often based on total carbon content).

8.SM.11.3.3 Metric Values for Nitrous Oxide

The indirect effect of increased N_2O abundance on CH_4 changes via stratospheric ozone, UV fluxes and OH levels is included in GWPs and GTPs. The reduction in CH_4 (–36 molecules per +100 molecules N_2O) offsets some of the climate impact from N_2O emissions. The AGWP becomes

$$AGWP_{N_2O}(H) = A_{N_2O}\left(1-0.36(1+f_1+f_2)\frac{RE_{CH_4}}{RE_{N_2O}}\right)\tau(1-e^{-H/\tau}) \quad (8.SM.20)$$

where f_1 and f_2 are the indirect effects for CH_4. The AGTP is modified in a similar way.

8.SM.11.4 Time Horizons

In previous IPCC assessments, GWP values were given for 20-, 100- and 500-year time horizons, while here we only use 20 and 100 years. Instead of using GWP values for 500 years we show the response to emissions of some extremely long-lived gases such as PFCs; see Figure 8.SM.5. Once these gases are emitted they stay in the atmosphere and contribute to warming on very long time scales (99% of an emission of PFC-14 is still in the atmosphere after 500 years). For comparison

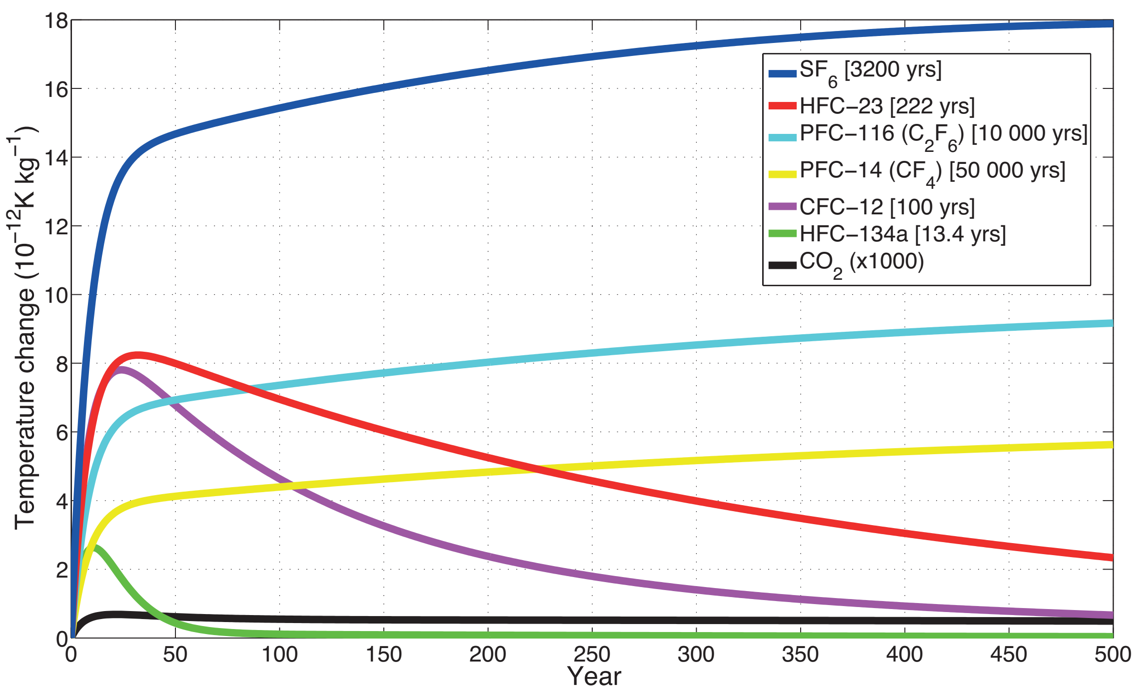

Figure 8.SM.5 | Temperature response due to 1-kg pulse emissions of greenhouse gases with a range of lifetimes (given in parentheses). Calculated with a temperature impulse response function taken from Boucher and Reddy (2008) which has a climate sensitivity of 1.06 K (W m^{-2})$^{-1}$, equivalent to a 3.9 K equilibrium response to 2 × CO_2 (unit for carbon dioxide is kg CO_2).

we also include gases with lifetimes of the order of centuries down to a decade. A 1 kg pulse of SF_6 has a temperature effect after 500 years that is of the order of 35,000 larger than that of CO_2. The corresponding numbers for CF_4 and C_2F_6 are 11,000 and 18,000, respectively. There are large uncertainties related to temperature responses (as well as the CO_2 response) on time-scales of centuries, but these results nevertheless indicate the persistence and long-lived warming effects of these gases.

One reason for not using a time horizon of 500 years is the increasing uncertainty in radiative efficiency, carbon uptake and ambiguity in the interpretation of GWP_{500}, especially for gases with short adjustment times relative to the time scale of the CO_2 perturbation. As explained in Section 8.7.1.2, the GWP gives the ratio of two integrals: one of a pulse of a non-CO_2 gas that decays to zero and that of the CO_2 response for which 20 to 40% of a pulse remains in the atmosphere for centuries. Figure 8.SM.5 also shows that the temperature response to a pulse of the relatively short-lived HFC-134a is close to zero for several centuries before the 500-year time horizon, while the GWP_{500} is 371. This example highlights how the integrated nature of GWP means that the GWP value at a particular time may give misleading information about the climate impacts at that time, as the time scale used in the GWP becomes very different from the residence time of the emitted compound.

8.SM.12 Uncertainty Calculations for Global Warming Potential to Support Section 8.7.1

In the absence of detailed uncertainty assessment, a first estimate of uncertainty for a given function, f, and input parameters, x_i, can be based on a first-order Taylor expansion of the variance in f leading to the well-known adding in quadrature approximation (Morgan and Henrion, 1990),

$$\Delta f = \sqrt{\sum_i (\Delta f_i)^2} = \sqrt{\sum_i \left(\frac{\partial f}{\partial x_i}\Delta x_i\right)^2} \tag{8.SM.21}$$

where Δf represents the uncertainty of each term, defined as the sensitivity to a marginal change multiplied by the error in the term. This approximation assumes that the uncertainties are small, $\Delta x_i \ll x_i$, the uncertainties are normally distributed, f is smooth for the range of input values and, most importantly, the uncertainties are independent.

If f is a product of two terms ($f = xy$), then it can be shown that

$$\left(\frac{\Delta f}{f}\right)^2 = \left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 \tag{8.SM.22}$$

We estimate the uncertainty in $AGWP_{CO2}$ using the uncertainty in A_{CO2} and I_{CO2},

$$AGWP_{CO_2}(H) = A_{CO_2} I_{CO_2}(H)$$

where

$$I_{CO_2}(H) = \int_0^H IRF_{CO_2}(t)\,dt \tag{8.SM.23}$$

In the case of the AGWP for non-CO_2 species, the expression becomes

$$\Delta AGWP = \sqrt{\left(\frac{\partial AGWP}{\partial A}\right)^2 \Delta A^2 + \left(\frac{\partial AGWP}{\partial \tau}\right)^2 \Delta \tau^2}$$

for

$$f = AGWP(A, \tau) \tag{8.SM.24}$$

where the expressions for the AGWP are from Equations 8.SM.9, 8.SM.19 and 8.SM.20. The uncertainty in the AGWP for CO_2 is based on Equation 8.SM.23.

Table 8.SM.12 shows the uncertainty data and source used in the analysis. Many of the input parameters are given for a 1-σ range and we scale the uncertainty by 1.645 to convert to 90% confidence for consistency with rest of AR5. In some cases this represents a strong and uncertain assumption since the high-end uncertainties are not necessarily well defined. The estimated uncertainties should be seen as a rough first order evaluation to get an impression of the order of magnitude and the main contributions to total uncertainty.

Table 8.SM.13 shows the uncertainty for the AGWP of CO_2, CH_4, N_2O, CFC-11, CFC-12 and HFC-134a, Table 8.SM.14 shows the corresponding uncertainty for the GWPs, and Figure 8.SM.6 shows the contribution of each term Δf_i in Equation 8.SM.21 to the uncertainty. The uncertainty in AGWP is generally dominated by the perturbation lifetime, though this varies depending on the lifetime relative to the time horizon. The uncertainty in the $AGWP_{CH4}$ has an important contribution from the indirect effects, particularly the forcing from ozone changes. Except for CH_4, the uncertainty in the GWPs is dominated by the uncertainty in $AGWP_{CO2}$.

Table 8.SM.12 | Uncertainty data, assumptions and sources used for the analysis. Note that uncertainties are assumed to be normally distributed and further analysis is required to determine the correct distribution.

Term	Expected Value (*x*)	Uncertainty (±Δ*x*, 5 to 95%)	Notes
A_{CO2}	Table 8.A.1	10%, Section 8.3.1	
I_{CO2}	Joos et al. (2013)	Joos et al. (2013)	
A_{CH4}	Table 8.A.1	10%, Section 8.3.1	Value before adjusting for ozone and stratospheric H_2O
τ_{CH4}	Section 8.2.3.3	18.57%, Section 8.2.3.3	One standard deviation uncertainty of 1.4/12.4 scaled by 1.645 to convert to 90% confidence
f_1	0.5 Ozone, see Equation 8.SM.19	60%	Uncertainty is 0.2–0.8
f_2	0.15, see Equation 8.SM.19	71.43%, Table 8.6	Uncertainty is 0.02–0.12
A_{N2O}	Table 8.A.1	10%, Section 8.3.1	
τ_{N2O}	Table 8.A.1	12.99%, Prather et al. (2012), Section 8.2.3.4	One standard deviation uncertainty of 7.9% scaled by 1.645 to convert to 90% confidence
A_{CFC-11}	Table 8.A.1	10%, Section 8.3.1	
τ_{CFC-11}	Table 8.A.1	22.55%, Rigby et al. (2013)	One standard deviation uncertainty of 13.71% scaled by 1.645 to convert to 90% confidence
A_{CFC-12}	Table 8.A.1	10%, Section 8.3.1	
τ_{CFC-12}	Table 8.A.1	28.76%, Rigby et al. (2013)	One standard deviation uncertainty of 17.49% scaled by 1.645 to convert to 90% confidence
$A_{HFC-134a}$	Table 8.A.1	10%, Section 8.3.1	
$\tau_{HFC-134a}$	Table 8.A.1	17.9%, Prather et al. (2012)	One standard deviation uncertainty of 10.9% scaled by 1.645 to convert to 90% confidence

Table 8.SM.13 | The estimated uncertainty in the AGWP for CO_2, CH_4, CFC-11, CFC-12, and HFC-134a showing the results of the full uncertainty analysis ('Full') and the effects of adding the uncertainty of different terms one at a time in the order (from left to right) of the next largest contributions. All values (±Δ*x*) are percentages of the expected value, *x*, for a 90% confidence interval.

Time Horizon (years)	$\Delta AGWP_{CO2}$			$\Delta AGWP_{CH4}$				$\Delta AGWP_{N2O}$			
	$+I_{CO2}$	$+A_{CO2}$	Full	$+f_i$	$+\tau_{CH4}$	$+A_{CH4}$	Full	$+A_{N2O}$	$+\tau_{CH4}$	$+CH_4$	Full
20	14	18	18	19	22	24	24	11	11	11	11
100	25	26	26	19	27	29	29	11	12	12	12
500	28	30	30	19	27	29	29	11	26	16	16

Time Horizon (years)	$\Delta AGWP_{CFC-11}$			$\Delta AGWP_{CFC-12}$			$\Delta AGWP_{HFC-134a}$		
	$+\tau_{CFC-11}$	$+A_{CFC-11}$	Full	$+\tau_{CFC-12}$	$+A_{CFC-12}$	Full	$+\tau_{HFC-134a}$	$+A_{HFC-134a}$	Full
20	5	11	11	3	10	10	10	14	14
100	16	19	19	12	16	16	18	20	20
500	23	25	25	28	30	30	18	21	21

Table 8.SM.14 | The estimated uncertainty in the GWP for CH_4, N_2O, CFC-11, CFC-12, and HFC-134a showing the results of the full uncertainty analysis ('Full') and the effects of adding the uncertainty of different terms one at a time in the order (from left to right) of the next largest contributions. All values (±Δ*x*) are percentages of the expected value, *x*, for a 90% confidence interval. $+CO_2$ represents the uncertainty in $AGWP_{CO2}$.

Time Horizon (years)	ΔGWP_{CH4}					ΔGWP_{N2O}				
	$+CO_2$	$+f_i$	$+\tau_{CH4}$	$+A_{CH4}$	Full	$+CO_2$	$+A_{N2O}$	$+\tau_{CH4}$	$+CH_4$	Full
20	18	26	28	30	30	18	21	21	21	21
100	26	33	38	39	39	26	29	29	29	29
500	30	35	40	41	41	30	32	34	34	34

Time Horizon (years)	ΔGWP_{CFC-11}				ΔGWP_{CFC-12}				$\Delta GWP_{HFC-134a}$			
	$+CO_2$	$+\tau_{CFC-11}$	$+A_{CFC-11}$	Full	$+CO_2$	$+\tau_{CFC-12}$	$+A_{CFC-12}$	Full	$+CO_2$	$+\tau_{HFC-134a}$	$+A_{HFC-134a}$	Full
20	18	18	21	21	18	18	20	20	18	20	23	23
100	26	31	33	33	26	29	31	31	26	32	33	33
500	30	37	39	39	30	41	42	42	30	35	36	36

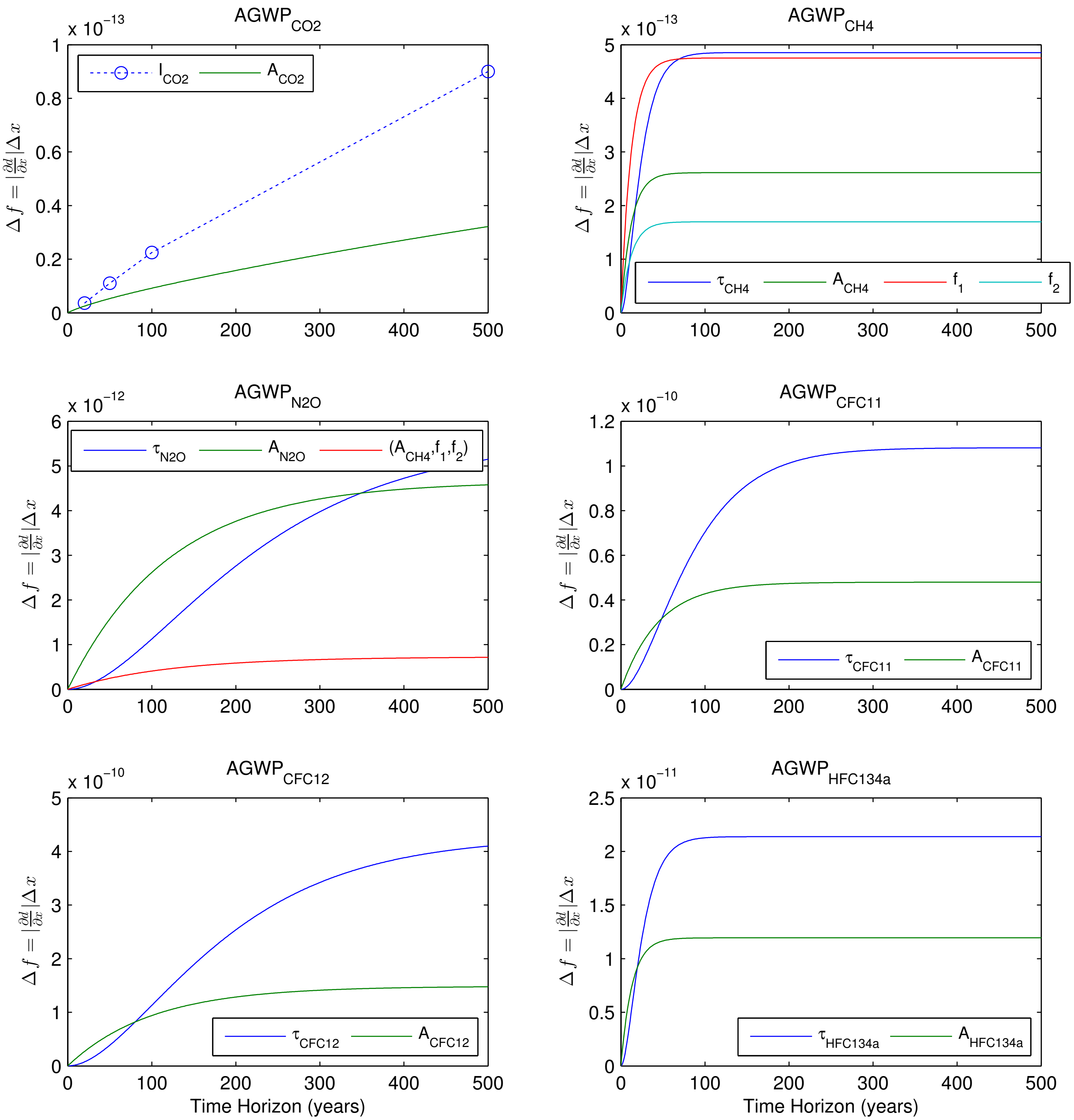

Figure 8.SM.6 | The contribution of each term to the uncertainty in the AGWP, ΔAGWP is obtained by adding each term in quadrature according to Equation 8.SM.21. I_{CO2} has data available only for four data points. For AGWP$_{N2O}$ the contribution from the radiative efficiency and indirect effect of CH_4 are combined in quadrature. In uncertainty analysis, the contributions are added in quadrature (Equation 8.SM.21), which will amplify the differences.

8.SM.13 Calculations of Metric Values for Halocarbons to Support Section 8.7.2

The method used to calculate the radiative efficiencies (REs) and GWPs in Table 8.A.1 is discussed briefly here. More details are available at the following website: http://cicero.uio.no/halocarbonmetrics/.

8.SM.13.1 Lifetimes

The lifetime of each compound is taken from WMO (2011) when available. For some compounds, when WMO lifetimes are not available, lifetimes are taken from the published literature (sources of lifetime estimates are given here: http://cicero.uio.no/halocarbonmetrics/). For a few compounds, lifetimes could not be found in the literature and only the RE (and not the GWP) could be calculated. The REs of these compounds, assuming a homogeneous mixing in the atmosphere, are given in Table 8.SM.15.

8.SM.13.2 Absorption Cross Sections

The absorption cross sections used for the RE and GWP calculations come from a variety of sources, including the High-Resolution Transmission (HITRAN)-2008 (Rothman et al., 2009) and Gestion et Etude des Informations Spectroscopiques Atmosphériques (GEISA)-2011 (Jacquinet-Husson et al., 2011) databases, authors of published papers, and supplementary material to published papers. A table that lists the absorption cross-sections used to calculate the RE for each compound can be found at the following website: http://cicero.uio.no/halocarbonmetrics/. Experimental absorption cross-sections have been used for the majority of compounds, but for a few compounds theoretical spectra were used because of unavailability of experimental spectra.

8.SM.13.3 Instantaneous Radiative Efficiency

The simple method from Pinnock et al. (1995) has been adopted here for the calculation of RE, except that a revised version of the Pinnock et al. curve has been used. This ensures a common method for deriving RE from absorption cross sections, and hence greater internal consistency, in contrast to the many different methods/assumptions used for calculation of RE used in the literature. The new curve, at 1 cm^{-1} spectral resolution (rather than the original 10 cm^{-1} resolution used in Pinnock et al., (1995) is based on calculations with the Oslo Line-by-Line (LBL) model (Myhre et al., 2006), and is shown in Figure 8.SM.7.

Table 8.SM.15 | Calculated radiative efficiencies (REs) for compounds where lifetime estimates are unknown. Note that homogeneous mixing in the atmosphere is assumed; hence the REs presented here are probably upper estimates.

Common Name or Chemical Name	Chemical Formula	Radiative Efficiency (W m^{-2} ppb^{-1})
1,1,1,3,3,3-Hexafluoro-2-(trifluoromethyl)-2-propanol	$(CF_3)_3COH$	0.38
HG′-10	$CH_3OCF_2OCH_3$	0.26
HG′-20	$CH_3O(CF_2O)_2CH_3$	0.72
HG′-30	$CH_3O(CF_2O)_3CH_3$	1.14
HFE-338mec3	$CF_3CFHCF_2OCF_2H$	0.51
Fluoromethyl carbonofluoridate	$FCOOCFH_2$	0.19
Difluoromethyl carbonofluoridate	$FCOOCF_2H$	0.33
Trifluoromethyl carbonofluoridate	$FCOOCF_3$	0.32
Perfluoroethyl carbonofluoridate	$FCOOCF_2CF_3$	0.48
2,2,2-Trifluoroethyl carbonofluoridate	$FCOOCH_2CF_3$	0.33
Perfluoropropyl carbonofluoridate	$FCOOCF_2CF_2CF_3$	0.53
Trifluoromethyl 2,2,2-trifluoroacetate	CF_3COOCF_3	0.49
Perfluoroethyl 2,2,2-trifluoroacetate	$CF_3COOCF_2CF_3$	0.62
1,1,1,3,3,3-Hexafluoropropan-2-yl 2,2,2-trifluoroacetate	$CF_3COOCH(CF_3)_2$	0.49
Vinyl 2,2,2-trifluoroacetate	$CF_3COOCH{=}CH_2$	0.39
Allyl 2,2,2-trifluoroacetate	$CF_3COOCH_2CHCH_2$	0.35
Phenyl 2,2,2-trifluoroacetate	CF_3COOPh	0.39
Methyl 2-fluoroacetate	$H_2CFCOOCH_3$	0.08
Difluoromethyl 2,2-difluoroacetate	$HCF_2COOCHF_2$	0.44
4,4,4-Trifluorobutanal	$CF_3(CH_2)_2CHO$	0.16

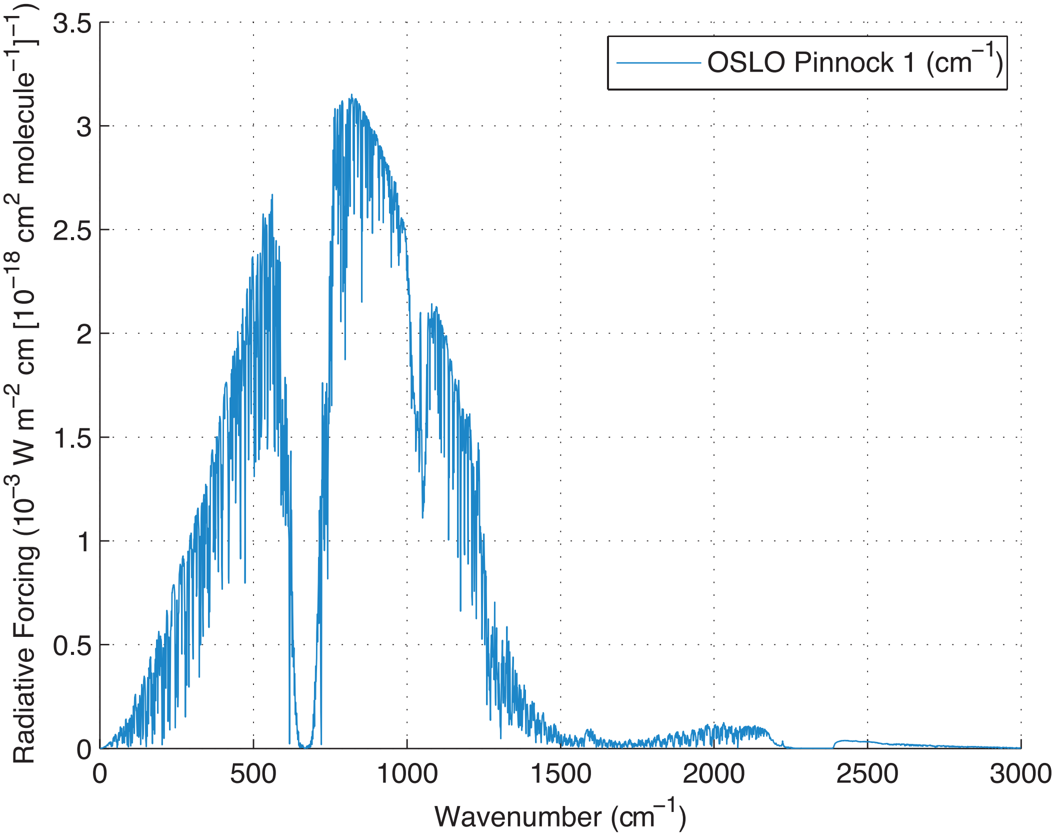

Figure 8.SM.7 | Radiative forcing efficiency (for a 0 to 1 ppbv increase in mixing ratio) per unit cross section calculated with the Oslo Line-by-Line (LBL) model.

8.SM.13.4 Stratospheric Temperature Adjustment

The revised Pinnock et al. curve shown in Figure 8.SM.7 applies for instantaneous radiative forcing efficiency. To take into account stratospheric temperature adjustment, a factor has been applied based on results from previous studies. For most compounds, the instantaneous REs have been increased by 10% (Pinnock et al., 1995; Myhre and Stordal, 1997; Jain et al., 2000; Naik et al., 2000; Forster et al., 2005) to account for stratospheric temperature adjustment. For a few selected compounds, explicit model calculations have been carried out using the Oslo LBL model (Myhre et al., 2006). These calculations show increases of 9.1%, 10.5%, and 10.5% for CFC-11, CFC-12 and CF_4, respectively, when taking into account the stratospheric temperature adjustment, while there is a reduction of 5.0% for HFC-41. The assumed increase of 10% for the remaining compounds is considered a good approximation, based on our calculations and the literature (e.g., Pinnock et al., 1995; Myhre and Stordal, 1997).

8.SM.13.5 Lifetime Correction

Fractional correction factors to the RE, to take into account the non-uniform mixing in the atmosphere, have previously been presented in Freckleton et al. (1998) and Sihra et al. (2001). Here, the method of Sihra et al. (2001) has been extended by including the results of Sellevag et al. (2004), and by carrying out new calculations using essentially the same models (Oslo CTM2, Søvde et al., 2008); and Oslo Broadband model, (Myhre and Stordal, 1997) and a similar setup as in Sellevag et al. (2004). One fractional correction curve has been calculated for the compounds dominated by loss through photolysis in the stratosphere, and one curve for compounds that are lost mainly by reaction with OH. The first curve was calculated by applying an exponential curve fit which gives the formula $f(\tau) = 1 - 0.1826\ \tau^{-0.3339}$, where f is the fractional correction and τ is the lifetime in years. The empirical fit for the latter curve was constrained to form an *S*-shaped curve with the formula $f(\tau) = (a\tau)^b / (1 + c\tau^d)$, and the constants have values a = 2.962, b = 0.9312, c = 2.994 and d = 0.9302. The resulting two curves are shown in Figure 8.SM.8 and have been applied when calculating REs and GWPs for compounds where the lifetime is known. For shorter-lived compounds (less than about 2 to 3 years), the fractional correction depends on where the compound is emitted and so no unique curve can be defined. Here it has been assumed that the geographical distribution is similar to the approach in Sellevag et al. (2004). These fractional corrections have been made to the RE after the instantaneous RE has been modified for stratospheric temperature adjustment as described in the paragraph above.

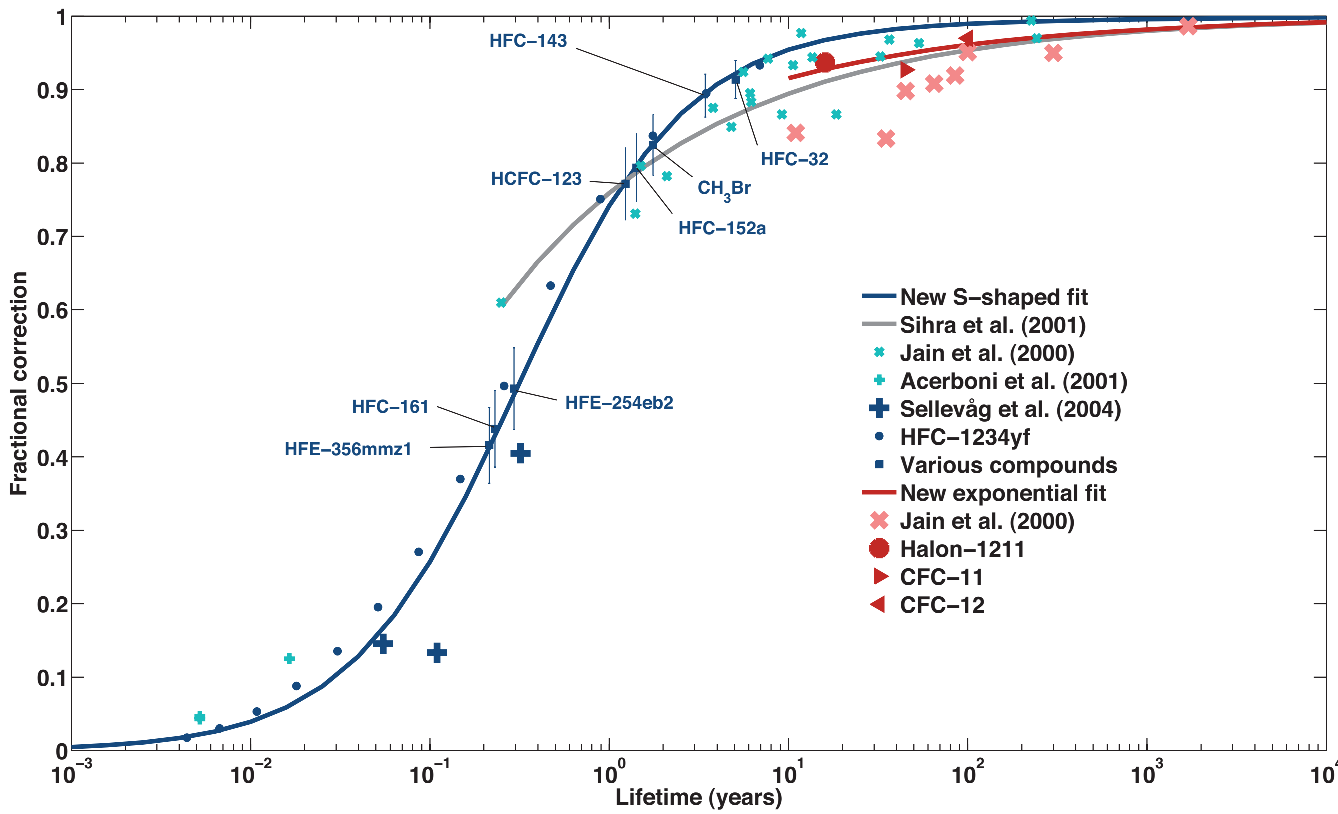

Figure 8.SM.8 | Factor needed to correct radiative efficiency (RE) to account for non-uniform vertical and horizontal distribution versus atmospheric lifetime. The red symbols are for compounds whose main loss mechanism is stratospheric photolysis while the blue symbols are for compounds that are lost in the troposphere mainly by reaction with OH. Dark blue symbols have been used in the calculation of the *S*-shaped fit and dark red symbols have been used in the calculation of the exponential fit. Light blue and light red symbols are shown for comparison. The curve from Sihra et al. (2001) represents an empirical least squares fit to the fractional correction factors from Jain et al. (2000). For compounds where several different absorption bands have been used in the RF calculations, both the mean and the standard deviation of the fractional corrections are shown.

8.SM.14 Metric Values for Other Near-Term Climate Forcers to Support Section 8.7.2

Derwent et al. (2001) report a GWP_{100} of 5.8 for the effects of H_2 emissions on CH_4 and ozone. For global emissions of SO_2 Fuglestvedt et al. (2010) calculated GWPs of –140 and –40 for 20 and 100 years, respectively. The GTPs are –41 and –6.9 for the same time horizons (for both metrics the values are given on an SO_2 basis and account only for the aerosol radiation interaction of sulphate). For SO_2 Shindell et al. (2009) calculated –22 ± 20 (aerosol–radiation interaction only) and –76 ± 69 (aerosol–radiation interaction and aerosol–cloud interactions) for GWP_{100}, and –78 ± 70 and –268 ± 241 for GWP_{20}. For NH_3 Shindell et al. (2009) calculated –19 ± 22 (aerosol-radiation interaction only) and –15 ± 18 (aerosol–radiation interaction and aerosol–cloud interactions) for GWP_{100}, and –65 ± 76 and –53 ± 62 for GWP_{20}. Due to competition for ammonium between nitrate and sulphate, the net aerosol forcing from either SO_2 or NH_3 emissions is the residual of larger responses of opposite signs, which leads to the high uncertainty in their numbers. (These values are based on IRF for CO_2 from AR4.) The GWP_{100} and GTP_{100} values can be scaled by 0.94 and 0.92, respectively, to account for updated values for the reference gas CO_2.

8.SM.15 Metric Values for Halocarbons Including Climate–Carbon Feedback for Carbon Dioxide to Support Section 8.7.2

Table 8.SM.16 | GWP and GTP with climate–carbon feedbacks included for halocarbons. The additional effect (delta) and the total effect are given. (Climate–carbon feedbacks in response to the reference gas CO_2 are always included).

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
CFC-11										
Delta	3.04E-12	**122**	6.32E-11	**689**	1.29E-13	**189**	4.32E-13	**701**	6.32E-13	**1156**
Total	1.75E-10	**7020**	4.91E-10	**5352**	4.84E-12	**7078**	3.45E-12	**5589**	1.91E-12	**3491**
CFC-12										
Delta	4.53E-12	**182**	1.20E-10	**1308**	1.94E-13	**283**	7.45E-13	**1208**	1.34E-12	**2459**
Total	2.74E-10	**10,976**	1.06E-09	**11,547**	7.90E-12	**11,549**	7.50E-12	**12,160**	5.96E-12	**10,907**
CFC-13										
Delta	4.40E-12	**177**	1.43E-10	**1558**	1.89E-13	**277**	8.09E-13	**1312**	1.76E-12	**3221**
Total	2.75E-10	**11,040**	1.42E-09	**15,451**	8.18E-12	**11,960**	9.58E-12	**15,530**	1.05E-11	**19,144**
CFC-113										
Delta	2.75E-12	**110**	6.99E-11	**762**	1.17E-13	**171**	4.41E-13	**716**	7.69E-13	**1407**
Total	1.65E-10	**6600**	6.04E-10	**6586**	4.72E-12	**6902**	4.29E-12	**6963**	3.22E-12	**5880**
CFC-114										
Delta	3.18E-12	**127**	9.38E-11	**1023**	1.36E-13	**199**	5.55E-13	**900**	1.11E-12	**2026**
Total	1.96E-10	**7839**	8.82E-10	**9615**	5.74E-12	**8385**	6.12E-12	**9922**	5.79E-12	**10,579**
CFC-115										
Delta	2.37E-12	**95**	7.81E-11	**851**	1.02E-13	**149**	4.39E-13	**712**	9.69E-13	**1772**
Total	1.49E-10	**5954**	7.81E-10	**8516**	4.42E-12	**6463**	5.25E-12	**8517**	5.88E-12	**10,749**
HCFC-21										
Delta	4.72E-13	**19**	2.91E-12	**32**	1.71E-14	**25**	2.16E-14	**35**	2.03E-14	**37**
Total	1.40E-11	**562**	1.65E-11	**179**	1.49E-13	**217**	3.75E-14	**61**	3.14E-14	**57**
HCFC-22										
Delta	2.88E-12	**115**	3.13E-11	**342**	1.18E-13	**172**	2.46E-13	**399**	2.44E-13	**446**
Total	1.35E-10	**5395**	1.93E-10	**2106**	2.99E-12	**4368**	7.59E-13	**1230**	3.87E-13	**708**
HCFC-122										
Delta	1.99E-13	**8**	1.17E-12	**13**	7.06E-15	**10**	8.66E-15	**14**	8.13E-15	15
Total	5.63E-12	**226**	6.60E-12	**72**	5.51E-14	**81**	1.49E-14	**24**	1.26E-14	23
HCFC-122a										
Delta	7.28E-13	**29**	5.00E-12	**54**	2.75E-14	**40**	3.78E-14	**61**	3.54E-14	**65**
Total	2.43E-11	**975**	2.87E-11	**312**	3.19E-13	**466**	6.77E-14	**110**	5.50E-14	**101**
HCFC-123										
Delta	2.61E-13	**10**	1.57E-12	**17**	9.35E-15	**14**	1.16E-14	**19**	1.09E-14	**20**
Total	7.54E-12	**302**	8.85E-12	**96**	7.64E-14	**112**	2.01E-14	**33**	1.69E-14	**31**
HCFC-123a										
Delta	9.98E-13	**40**	7.12E-12	**78**	3.82E-14	**56**	5.42E-14	**88**	5.08E-14	**93**
Total	3.47E-11	**1390**	4.10E-11	**447**	4.89E-13	**715**	9.86E-14	**160**	7.89E-14	**144**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
HCFC-124										
Delta	1.24E-12	**50**	9.96E-12	**109**	4.87E-14	**71**	7.70E-14	**125**	7.24E-14	**132**
Total	4.79E-11	**1920**	5.82E-11	**635**	8.12E-13	**1187**	1.52E-13	**246**	1.13E-13	**206**
HCFC-132c										
Delta	8.93E-13	**36**	6.50E-12	**71**	3.43E-14	**50**	4.96E-14	**80**	4.65E-14	**85**
Total	3.16E-11	**1268**	3.75E-11	**409**	4.61E-13	**674**	9.10E-14	**148**	7.23E-14	**132**
HCFC-141b										
Delta	1.48E-12	**59**	1.43E-11	**156**	5.99E-14	**88**	1.12E-13	**182**	1.08E-13	**197**
Total	6.51E-11	**2608**	8.60E-11	**938**	1.33E-12	**1941**	2.80E-13	**453**	1.69E-13	**309**
HCFC-142b										
Delta	2.53E-12	**101**	3.33E-11	**363**	1.05E-13	**153**	2.56E-13	**415**	2.75E-13	**502**
Total	1.28E-10	**5125**	2.15E-10	**2345**	3.11E-12	**4546**	1.10E-12	**1787**	4.69E-13	**858**
HCFC-225ca										
Delta	4.02E-13	**16**	2.51E-12	**27**	1.47E-14	**21**	1.87E-14	**30**	1.75E-14	**32**
Total	1.21E-11	**485**	1.42E-11	**155**	1.31E-13	**192**	3.25E-14	**53**	2.72E-14	**50**
HCFC-225cb										
Delta	1.23E-12	**49**	9.92E-12	**108**	4.85E-14	**71**	7.67E-14	**124**	7.22E-14	**132**
Total	4.77E-11	**1913**	5.80E-11	**633**	8.09E-13	**1183**	1.51E-13	**245**	1.12E-13	**205**
(E)-1-Chloro-3,3,3-trifluoroprop-1-ene										
Delta	5.31E-15	**<1**	2.97E-14	**<1**	1.82E-16	**<1**	2.17E-16	**<1**	2.04E-16	<1
Total	1.42E-13	**6**	1.66E-13	**2**	1.28E-15	**2**	3.71E-16	**1**	3.16E-16	1
HFC-23										
Delta	4.45E-12	**178**	1.34E-10	**1459**	1.91E-13	**279**	7.85E-13	**1272**	1.59E-12	**2913**
Total	2.75E-10	**11,005**	1.27E-09	**13,856**	8.07E-12	**11,802**	8.78E-12	**14,232**	8.54E-12	**15,622**
HFC-32										
Delta	1.67E-12	**67**	1.29E-11	**141**	6.52E-14	**95**	9.91E-14	**161**	9.31E-14	**170**
Total	6.24E-11	**2502**	7.50E-11	**817**	9.97E-13	**1457**	1.88E-13	**305**	1.45E-13	**265**
HFC-41										
Delta	3.43E-13	**14**	2.27E-12	**25**	1.28E-14	**19**	1.70E-14	**28**	1.60E-14	**29**
Total	1.10E-11	**441**	1.29E-11	**141**	1.34E-13	**195**	3.01E-14	**49**	2.48E-14	**45**
HFC-125										
Delta	2.83E-12	**113**	4.79E-11	**522**	1.19E-13	**174**	3.49E-13	**566**	4.37E-13	**798**
Total	1.55E-10	**6207**	3.39E-10	**3691**	4.08E-12	**5971**	2.19E-12	**3543**	9.66E-13	**1766**
HFC-134										
Delta	2.06E-12	**82**	2.03E-11	**221**	8.31E-14	**122**	1.59E-13	**258**	1.54E-13	**282**
Total	9.14E-11	**3663**	1.23E-10	**1337**	1.90E-12	**2778**	4.13E-13	**670**	2.41E-13	**441**
HFC-134a										
Delta	1.97E-12	**79**	2.27E-11	**248**	8.07E-14	**118**	1.78E-13	**288**	1.80E-13	**329**
Total	9.45E-11	**3789**	1.42E-10	**1549**	2.17E-12	**3171**	6.11E-13	**991**	2.90E-13	**530**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
HFC-143										
Delta	9.18E-13	**37**	6.35E-12	**69**	3.48E-14	**51**	4.81E-14	**78**	4.51E-14	**82**
Total	3.09E-11	**1239**	3.64E-11	**397**	4.10E-13	**600**	8.63E-14	**140**	7.00E-14	**128**
HFC-143a										
Delta	3.05E-12	**122**	6.45E-11	**703**	1.29E-13	**189**	4.38E-13	**710**	6.50E-13	**1189**
Total	1.76E-10	**7064**	5.05E-10	**5508**	4.89E-12	**7146**	3.56E-12	**5771**	2.02E-12	**3693**
HFC-152										
Delta	5.73E-14	**2**	3.27E-13	**4**	.1.99E-15	**3**	2.40E-15	**4**	2.25E-15	**4**
Total	1.56E-12	**63**	1.83E-12	**20**	1.45E-14	**21**	4.10E-15	**7**	3.49E-15	**6**
HFC-152a										
Delta	4.46E-13	**18**	2.71E-12	**30**	1.61E-14	**23**	2.01E-14	**33**	1.89E-14	35
Total	1.31E-11	**524**	1.53E-11	**167**	1.35E-13	**198**	3.49E-14	**57**	2.93E-14	54
HFC-161										
Delta	1.29E-14	**1**	7.26E-14	**1**	4.44E-16	**1**	5.30E-16	**1**	4.99E-16	**1**
Total	3.46E-13	**14**	4.06E-13	**4**	3.14E-15	**5**	9.06E-16	**1**	7.72E-16	**1**
HFC-227ca										
Delta	2.36E-12	**95**	3.99E-11	**435**	9.91E-14	**145**	2.91E-13	**472**	3.64E-13	**665**
Total	1.29E-10	**5175**	2.82E-10	**3077**	3.41E-12	**4978**	1.82E-12	**2954**	8.05E-13	**1472**
HFC-227ea										
Delta	2.40E-12	**96**	4.69E-11	**512**	1.01E-13	**148**	3.27E-13	**531**	4.56E-13	**835**
Total	1.36E-10	**5454**	3.54E-10	**3860**	3.72E-12	**5431**	2.45E-12	**3967**	1.25E-12	**2294**
HFC-236cb										
Delta	1.85E-12	**74**	2.12E-11	**231**	7.59E-14	**111**	1.66E-13	**269**	1.67E-13	**305**
Total	8.86E-11	**3550**	1.32E-10	**1438**	2.02E-12	**2953**	5.58E-13	**904**	2.68E-13	**490**
HFC-236ea										
Delta	2.28E-12	**92**	2.39E-11	**261**	9.30E-14	**136**	1.88E-13	**305**	1.84E-13	**337**
Total	1.05E-10	**4203**	1.46E-10	**1596**	2.27E-12	**3322**	5.41E-13	**878**	2.91E-13	**532**
HFC-236fa										
Delta	2.84E-12	**114**	8.64E-11	**942**	1.22E-13	**178**	5.05E-13	**818**	1.03E-12	**1890**
Total	1.76E-10	**7054**	8.25E-10	**8998**	5.18E-12	**7575**	5.69E-12	**9220**	5.61E-12	**10,267**
HFC-245ca										
Delta	1.62E-12	**65**	1.35E-11	**147**	6.39E-14	**93**	1.04E-13	**169**	9.85E-14	**180**
Total	6.42E-11	**2575**	7.91E-11	**863**	1.14E-12	**1663**	2.13E-13	**345**	1.53E-13	**281**
HFC-245cb										
Delta	2.94E-12	**118**	6.20E-11	**676**	1.24E-13	**182**	4.21E-13	**683**	6.25E-13	**1144**
Total	1.70E-10	**6795**	4.86E-10	**5298**	4.70E-12	**6875**	3.42E-12	**5552**	1.94E-12	**3553**
HFC-245ea										
Delta	6.73E-13	**27**	4.57E-12	**50**	2.54E-14	**37**	3.45E-14	**56**	3.23E-14	**59**
Total	2.22E-11	**890**	2.61E-11	**285**	2.84E-13	**415**	6.14E-14	**100**	5.02E-14	**92**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
HFC-245eb										
Delta	8.37E-13	**34**	5.64E-12	**61**	3.15E-14	**46**	4.25E-14	**69**	3.99E-14	73
Total	2.74E-11	**1099**	3.23E-11	**352**	3.46E-13	**506**	7.56E-14	**123**	6.19E-14	113
HFC-245fa										
Delta	1.79E-12	**72**	1.59E-11	**174**	7.14E-14	**104**	1.24E-13	**202**	1.18E-13	**216**
Total	7.46E-11	**2992**	9.47E-11	**1032**	1.42E-12	**2079**	2.76E-13	**447**	1.84E-13	**337**
HFC-263fb										
Delta	2.50E-13	**10**	1.49E-12	**16**	8.93E-15	**13**	1.10E-14	**18**	1.04E-14	**19**
Total	7.18E-12	**288**	8.42E-12	**92**	7.20E-14	**105**	1.91E-14	**31**	1.61E-14	**29**
HFC-272ca										
Delta	4.31E-13	**17**	2.82E-12	**31**	1.60E-14	**23**	2.11E-14	**34**	1.98E-14	**36**
Total	1.36E-11	**547**	1.60E-11	**175**	1.62E-13	**236**	3.72E-14	**60**	3.07E-14	**56**
HFC-329p										
Delta	2.09E-12	**84**	3.55E-11	**387**	8.79E-14	**128**	2.59E-13	**420**	3.24E-13	**593**
Total	1.15E-10	**4594**	2.52E-10	**2742**	3.03E-12	**4423**	1.63E-12	**2638**	7.21E-13	**1318**
HFC-365mfc										
Delta	1.57E-12	**63**	1.48E-11	**161**	6.33E-14	**93**	1.16E-13	**188**	1.11E-13	**203**
Total	6.79E-11	**2724**	8.86E-11	**966**	1.36E-12	**1986**	2.77E-13	**450**	1.73E-13	**317**
HFC-43-10mee										
Delta	2.20E-12	**88**	2.80E-11	**305**	9.09E-14	**133**	2.16E-13	**351**	2.28E-13	**417**
Total	1.10E-10	**4403**	1.79E-10	**1952**	2.63E-12	**3851**	8.78E-13	**1424**	3.82E-13	**698**
HFC-1132a										
Delta	1.51E-16	**<1**	8.44E-16	**<1**	5.18E-18	**<1**	6.16E-18	**<1**	5.79E-18	**<1**
Total	4.04E-15	**<1**	4.73E-15	**<1**	3.61E-17	**<1**	1.05E-17	**<1**	8.98E-18	**<1**
HFC-1141										
Delta	6.04E-17	**<1**	3.38E-16	**<1**	2.07E-18	**<1**	2.47E-18	**<1**	2.32E-18	**<1**
Total	1.62E-15	**<1**	1.90E-15	**<1**	1.44E-17	**<1**	4.21E-18	**<1**	3.60E-18	**<1**
(Z)-HFC-1225ye										
Delta	8.31E-16	**<1**	4.65E-15	**<1**	2.85E-17	**<1**	3.39E-17	**<1**	3.19E-17	**<1**
Total	2.22E-14	**1**	2.60E-14	**<1**	1.99E-16	**<1**	5.80E-17	**<1**	4.95E-17	**<1**
(E)-HFC-1225ye										
Delta	2.81E-16	**<1**	1.57E-15	**<1**	9.64E-18	**<1**	1.15E-17	**<1**	1.08E-17	<1
Total	7.52E-15	**<1**	8.81E-15	**<1**	6.72E-17	**<1**	1.96E-17	**<1**	1.67E-17	<1
(Z)-HFC-1234ze										
Delta	1.01E-15	**<1**	5.68E-15	**<1**	3.48E-17	**<1**	4.14E-17	**<1**	3.90E-17	**<1**
Total	2.71E-14	**1**	3.18E-14	**<1**	2.43E-16	**<1**	7.08E-17	**<1**	6.04E-17	**<1**
HFC-1234yf										
Delta	1.25E-15	**<1**	7.02E-15	**<1**	4.31E-17	**<1**	5.12E-17	**<1**	4.82E-17	**<1**
Total	3.35E-14	**1**	3.93E-14	**<1**	3.00E-16	**<1**	8.75E-17	**<1**	7.47E-17	**<1**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
(E)-HFC-1234ze										
Delta	3.40E-15	**<1**	1.90E-14	**<1**	1.17E-16	**<1**	1.39E-16	**<1**	1.30E-16	**<1**
Total	9.07E-14	**4**	1.06E-13	**1**	8.14E-16	**1**	2.37E-16	**<1**	2.02E-16	**<1**
(Z)-HFC-1336										
Delta	5.98E-15	**<1**	3.35E-14	**<1**	2.06E-16	**<1**	2.45E-16	**<1**	2.30E-16	**<1**
Total	1.60E-13	**6**	1.87E-13	**2**	1.44E-15	**2**	4.18E-16	**1**	3.56E-16	**1**
HFC-1243zf										
Delta	5.31E-16	**<1**	2.97E-15	**<1**	1.82E-17	**<1**	2.17E-17	**<1**	2.04E-17	**<1**
Total	1.42E-14	**1**	1.66E-14	**<1**	1.27E-16	**<1**	3.70E-17	**<1**	3.16E-17	**<1**
HFC-1345zfc										
Delta	4.49E-16	**<1**	2.51E-15	**<1**	1.54E-17	**<1**	1.83E-17	**<1**	1.72E-17	**<1**
Total	1.20E-14	**<1**	1.41E-14	**<1**	1.07E-16	**<1**	3.13E-17	**<1**	2.67E-17	**<1**
3,3,4,4,5,5,6,6,6-Nonafluorohex-1-ene										
Delta	4.84E-16	**<1**	2.71E-15	**<1**	1.66E-17	**<1**	1.98E-17	**<1**	1.86E-17	**<1**
Total	1.29E-14	**1**	1.52E-14	**<1**	1.16E-16	**<1**	3.38E-17	**<1**	2.88E-17	**<1**
3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooct-1-ene										
Delta	3.84E-16	**<1**	2.15E-15	**<1**	1.32E-17	**<1**	1.57E-17	**<1**	1.47E-17	**<1**
Total	1.03E-14	**<1**	1.20E-14	**<1**	9.19E-17	**<1**	2.68E-17	**<1**	2.29E-17	**<1**
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-Heptadecafluorodec-1-ene										
Delta	3.31E-16	**<1**	1.85E-15	**<1**	1.14E-17	**<1**	1.35E-17	**<1**	1.27E-17	**<1**
Total	8.86E-15	**<1**	1.04E-14	**<1**	7.92E-17	**<1**	2.31E-17	**<1**	1.97E-17	**<1**
Methyl chloroform										
Delta	4.02E-13	**16**	3.05E-12	**33**	1.56E-14	**23**	2.34E-14	**38**	2.20E-14	40
Total	1.48E-11	**594**	1.77E-11	**193**	2.32E-13	**339**	4.42E-14	**72**	3.42E-14	63
Carbon tetrachloride										
Delta	1.64E-12	**66**	2.66E-11	**290**	6.86E-14	**100**	1.96E-13	**318**	2.39E-13	**436**
Total	8.86E-11	**3550**	1.85E-10	**2019**	2.31E-12	**3378**	1.16E-12	**1887**	5.01E-13	**915**
Methyl chloride										
Delta	4.09E-14	**2**	2.42E-13	**3**	1.45E-15	**2**	1.78E-15	**3**	1.67E-15	**3**
Total	1.16E-12	**46**	1.36E-12	**15**	1.14E-14	**17**	3.07E-15	**5**	2.59E-15	**5**
Methylene chloride										
Delta	3.12E-14	**1**	1.78E-13	**2**	1.08E-15	**2**	1.30E-15	**2**	1.22E-15	**2**
Total	8.49E-13	**34**	9.95E-13	**11**	7.86E-15	**11**	2.23E-15	**4**	1.90E-15	**3**
Chloroform										
Delta	5.73E-14	**2**	3.27E-13	**4**	1.99E-15	**3**	2.40E-15	**4**	2.25E-15	**4**
Total	1.56E-12	**63**	1.83E-12	**20**	1.45E-14	**21**	4.10E-15	**7**	3.49E-15	**6**
1,2-Dichloroethane										
Delta	3.18E-15	**<1**	1.79E-14	**<1**	1.10E-16	**<1**	1.31E-16	**<1**	1.23E-16	**<1**
Total	8.56E-14	**3**	1.00E-13	**1**	7.77E-16	**1**	2.24E-16	**<1**	1.91E-16	**<1**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m⁻² yr kg⁻¹)	GWP 20-year	AGWP 100-year (W m⁻² yr kg⁻¹)	GWP 100-year	AGTP 20-year (K kg⁻¹)	GTP 20-year	AGTP 50-year (K kg⁻¹)	GTP 50-year	AGTP 100-year (K kg⁻¹)	GTP 100-year
Methyl bromide										
Delta	8.01E-15	<1	4.68E-14	1	2.82E-16	<1	3.44E-16	1	3.23E-16	1
Total	2.24E-13	9	2.63E-13	3	2.16E-15	3	5.91E-16	1	5.01E-16	1
Methylene bromide										
Delta	3.56E-15	<1	2.02E-14	<1	1.23E-16	<1	1.48E-16	<1	1.39E-16	<1
Total	9.66E-14	4	1.13E-13	1	8.90E-16	1	2.54E-16	<1	2.16E-16	<1
Halon-1201										
Delta	9.29E-13	37	7.16E-12	78	3.62E-14	53	5.50E-14	89	5.17E-14	95
Total	3.47E-11	1390	4.16E-11	454	5.54E-13	809	1.05E-13	170	8.04E-14	147
Halon-1202										
Delta	6.76E-13	27	4.50E-12	49	2.53E-14	37	3.38E-14	55	3.17E-14	58
Total	2.18E-11	875	2.57E-11	280	2.69E-13	393	5.99E-14	97	4.92E-14	90
Halon-1211										
Delta	2.34E-12	94	2.97E-11	324	9.67E-14	141	2.30E-13	373	2.42E-13	442
Total	1.17E-10	4684	1.90E-10	2070	2.80E-12	4091	9.28E-13	1504	4.04E-13	739
Halon-1301										
Delta	3.35E-12	134	7.91E-11	862	1.43E-13	208	5.15E-13	835	8.40E-13	1536
Total	1.98E-10	7935	6.56E-10	7154	5.61E-12	8194	4.68E-12	7581	3.12E-12	5703
Halon-2301										
Delta	4.89E-13	20	3.36E-12	37	1.85E-14	27	2.54E-14	41	2.38E-14	44
Total	1.63E-11	655	1.93E-11	210	2.14E-13	313	4.55E-14	74	3.70E-14	68
Halon-2311/Halothane										
Delta	1.38E-13	6	8.15E-13	9	4.90E-15	7	6.01E-15	10	5.64E-15	10
Total	3.91E-12	157	4.59E-12	50	3.84E-14	56	1.04E-14	17	8.75E-15	16
Halon-2401										
Delta	5.38E-13	22	3.58E-12	39	2.01E-14	29	2.69E-14	44	2.52E-14	46
Total	1.74E-11	696	2.04E-11	223	2.14E-13	312	4.77E-14	77	3.92E-14	72
Halon-2402										
Delta	1.68E-12	68	2.40E-11	262	7.01E-14	102	1.82E-13	296	2.04E-13	373
Total	8.76E-11	3511	1.59E-10	1734	2.19E-12	3207	8.90E-13	1443	3.70E-13	676
Nitrogen trifluoride										
Delta	5.19E-12	208	1.66E-10	1815	2.23E-13	326	9.48E-13	1537	2.04E-12	3733
Total	3.24E-10	12,987,000	1.64E-09	17,885	9.61E-12	14,049	1.11E-11	18,041	1.20E-11	21,852
Sulphur hexafluoride										
Delta	7.06E-12	283	2.37E-10	2580	3.03E-13	444	1.32E-12	2139	2.96E-12	5416
Total	4.44E-10	17,783	2.39E-09	26,087	1.32E-11	19,348	1.60E-11	25,934	1.84E-11	33,631
(Trifluoromethyl)sulphur pentafluoride										
Delta	5.46E-12	219	1.78E-10	1946	2.35E-13	343	1.01E-12	1633	2.21E-12	4039
Total	3.42E-10	13,698	1.78E-09	19,396	1.02E-11	14,855	1.20E-11	19,443	1.33E-11	24,271

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
Sulphuryl fluoride										
Delta	3.08E-12	124	5.84E-11	637	1.30E-13	190	4.12E-13	668	5.60E-13	1024
Total	1.74E-10	6965	4.34E-10	4732	4.71E-12	6885	2.96E-12	4805	1.46E-12	2671
PFC-14										
Delta	1.96E-12	79	6.64E-11	724	8.44E-14	123	3.69E-13	598	8.34E-13	1524
Total	1.24E-10	4954	6.74E-10	7349	3.69E-12	5396	4.49E-12	7286	5.23E-12	9563
PFC-116										
Delta	3.31E-12	133	1.12E-10	1216	1.42E-13	208	6.20E-13	1006	1.40E-12	2560
Total	2.08E-10	8344	1.13E-09	12,340	6.21E-12	9085	7.55E-12	12,243	8.76E-12	16,016
PFC-c216										
Delta	2.76E-12	111	9.26E-11	1010	1.19E-13	174	5.16E-13	837	1.16E-12	2119
Total	1.74E-10	6964	9.36E-10	10,208	5.18E-12	7576	6.26E-12	10,149	7.19E-12	13,151
PFC-218										
Delta	2.68E-12	107	8.97E-11	978	1.15E-13	168	5.00E-13	812	1.12E-12	2051
Total	1.68E-10	6752	9.06E-10	9878	5.02E-12	7344	6.06E-12	9826	6.95E-12	12,705
PFC-318										
Delta	2.87E-12	115	9.61E-11	1048	1.23E-13	180	5.36E-13	869	1.20E-12	2199
Total	1.80E-10	7221	9.71E-10	10,592	5.37E-12	7856	6.49E-12	10,530	7.47E-12	13,655
PFC-31-10										
Delta	2.77E-12	111	9.27E-11	1011	1.19E-13	174	5.17E-13	839	1.16E-12	2121
Total	1.74E-10	6981	9.37E-10	10,213	5.19E-12	7594	6.27E-12	10,160	7.18E-12	13,137
Perfluorocyclopentene										
Delta	6.63E-15	<1	3.72E-14	<1	2.28E-16	<1	2.71E-16	<1	2.55E-16	<1
Total	1.77E-13	7	2.08E-13	2	1.60E-15	2	4.63E-16	1	3.95E-16	1
PFC-41-12										
Delta	2.56E-12	103	8.59E-11	937	1.10E-13	161	4.79E-13	776	1.08E-12	1968
Total	1.61E-10	6448	8.70E-10	9484	4.80E-12	7017	5.81E-12	9422	6.70E-12	12,253
PFC-51-14										
Delta	2.38E-12	95	7.97E-11	869	1.02E-13	149	4.44E-13	720	9.97E-13	1823
Total	1.49E-10	5988	8.05E-10	8780	4.46E-12	6514	5.38E-12	8730	6.19E-12	11,316
PFC-61-16										
Delta	2.35E-12	94	7.88E-11	859	1.01E-13	148	4.39E-13	712	9.86E-13	1802
Total	1.48E-10	5922	7.96E-10	8681	4.41E-12	6443	5.32E-12	8631	6.12E-12	11,183
PFC-71-18										
Delta	2.29E-12	92	7.67E-11	837	9.84E-14	144	4.28E-13	694	9.60E-13	1756
Total	1.44E-10	5769	7.76E-10	8456	4.29E-12	6276	5.19E-12	8408	5.96E-12	10,894
PFC-91-18										
Delta	2.18E-12	87	7.26E-11	791	9.35E-14	137	4.05E-13	658	9.06E-13	1657
Total	1.37E-10	5476	7.32E-10	7977	4.07E-12	5954	4.90E-12	7943	5.59E-12	10,222

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m⁻² yr kg⁻¹)	GWP 20-year	AGWP 100-year (W m⁻² yr kg⁻¹)	GWP 100-year	AGTP 20-year (K kg⁻¹)	GTP 20-year	AGTP 50-year (K kg⁻¹)	GTP 50-year	AGTP 100-year (K kg⁻¹)	GTP 100-year
Perfluorodecalin(cis)										
Delta	2.19E-12	**88**	7.31E-11	**797**	9.42E-14	**138**	4.08E-13	**662**	9.13E-13	**1669**
Total	1.38E-10	**5515**	7.37E-10	**8033**	4.10E-12	**5997**	4.93E-12	**8000**	5.63E-12	**10,295**
Perfluorodecalin(trans)										
Delta	1.90E-12	**76**	6.35E-11	**692**	8.18E-14	**120**	3.55E-13	**575**	7.93E-13	**1450**
Total	1.20E-10	**4792**	6.40E-10	**6980**	3.56E-12	**5211**	4.29E-12	**6951**	4.89E-12	**8946**
PFC-1114										
Delta	1.03E-17	**<1**	5.78E-17	**<1**	3.55E-19	**<1**	4.22E-19	**<1**	3.96E-19	**<1**
Total	2.77E-16	**<1**	3.24E-16	**<1**	2.47E-18	**<1**	7.21E-19	**<1**	6.15E-19	**<1**
PFC-1216										
Delta	2.49E-16	**<1**	1.40E-15	**<1**	8.56E-18	**<1**	1.02E-17	**<1**	9.57E-18	**<1**
Total	6.67E-15	**<1**	7.82E-15	**<1**	5.97E-17	**<1**	1.74E-17	**<1**	1.48E-17	**<1**
Perfluorobuta-1,3-diene										
Delta	1.27E-17	**<1**	7.11E-17	**<1**	4.36E-19	**<1**	5.19E-19	**<1**	4.88E-19	**<1**
Total	3.40E-16	**<1**	3.99E-16	**<1**	3.04E-18	**<1**	8.86E-19	**<1**	7.57E-19	**<1**
Perfluorobut-1-ene										
Delta	3.25E-16	**<1**	1.82E-15	**<1**	1.11E-17	**<1**	1.33E-17	**<1**	1.25E-17	**<1**
Total	8.69E-15	**<1**	1.02E-14	**<1**	7.77E-17	**<1**	2.26E-17	**<1**	1.93E-17	**<1**
Perfluorobut-2-ene										
Delta	6.28E-15	**<1**	3.52E-14	**<1**	2.16E-16	**<1**	2.57E-16	**<1**	2.42E-16	**<1**
Total	1.68E-13	**7**	1.97E-13	**2**	1.51E-15	**2**	4.39E-16	**1**	3.74E-16	**1**
HFE-125										
Delta	5.18E-12	**208**	1.42E-10	**1549**	2.21E-13	**324**	8.68E-13	**1408**	1.62E-12	**2961**
Total	3.15E-10	**12,617**	1.28E-09	**13,951**	9.13E-12	**13,349**	9.01E-12	**14,615**	7.59E-12	**13,871**
HFE-134 (HG-00)										
Delta	5.51E-12	**221**	8.69E-11	**947**	2.31E-13	**337**	6.46E-13	**1047**	7.69E-13	1406
Total	2.96E-10	**11,857**	5.97E-10	**6512**	7.65E-12	**11,183**	3.67E-12	**5945**	1.55E-12	2837
HFE-143a										
Delta	1.33E-12	**53**	1.00E-11	**109**	5.16E-14	**75**	7.67E-14	**124**	7.19E-14	**132**
Total	4.86E-11	**1947**	5.80E-11	**632**	7.47E-13	**1091**	1.43E-13	**232**	1.12E-13	**205**
HFE-227ea										
Delta	3.88E-12	**156**	8.49E-11	**926**	1.65E-13	**241**	5.70E-13	**924**	8.70E-13	**1590**
Total	2.26E-10	**9058**	6.77E-10	**7377**	6.31E-12	**9224**	4.79E-12	**7773**	2.85E-12	**5217**
HCFE-235ca2 (enflurane)										
Delta	1.54E-12	**62**	1.12E-11	**122**	5.92E-14	**87**	8.55E-14	**139**	8.01E-14	**147**
Total	5.45E-11	**2185**	6.47E-11	**705**	7.95E-13	**1162**	1.57E-13	**254**	1.25E-13	**228**
HCFE-235da2 (isoflurane)										
Delta	1.37E-12	**55**	9.51E-12	**104**	5.21E-14	**76**	7.20E-14	**117**	6.75E-14	**123**
Total	4.63E-11	**1854**	5.45E-11	**595**	6.14E-13	**898**	1.29E-13	**209**	1.05E-13	**192**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	**GWP 20-year**	AGWP 100-year (W m^{-2} yr kg^{-1})	**GWP 100-year**	AGTP 20-year (K kg^{-1})	**GTP 20-year**	AGTP 50-year (K kg^{-1})	**GTP 50-year**	AGTP 100-year (K kg^{-1})	GTP 100-year
HFE-236ca										
Delta	4.72E-12	**189**	6.86E-11	**748**	1.97E-13	**287**	5.19E-13	**842**	5.87E-13	**1074**
Total	2.47E-10	**9901**	4.58E-10	**4990**	6.23E-12	**9105**	2.62E-12	**4241**	1.09E-12	**1985**
HFE-236ea2 (desflurane)										
Delta	3.10E-12	**124**	3.22E-11	**351**	1.26E-13	**184**	2.53E-13	**410**	2.48E-13	**453**
Total	1.42E-10	**5678**	1.97E-10	**2143**	3.05E-12	**4463**	7.17E-13	**1163**	3.90E-13	**713**
HFE-236fa										
Delta	2.07E-12	**83**	1.82E-11	**199**	8.24E-14	**120**	1.42E-13	**230**	1.35E-13	**247**
Total	8.56E-11	**3431**	1.08E-10	**1177**	1.61E-12	**2358**	3.10E-13	**503**	2.10E-13	**384**
HFE-245cb2										
Delta	1.65E-12	**66**	1.25E-11	**136**	6.41E-14	**94**	9.58E-14	**155**	8.99E-14	**164**
Total	6.06E-11	**2430**	7.25E-11	**790**	9.41E-13	**1376**	1.80E-13	**292**	1.40E-13	**256**
HFE-245fa1										
Delta	1.86E-12	**74**	1.55E-11	**169**	7.34E-14	**107**	1.21E-13	**196**	1.14E-13	**208**
Total	7.41E-11	**2970**	9.15E-11	**997**	1.32E-12	**1932**	2.48E-13	**402**	1.77E-13	**324**
HFE-245fa2										
Delta	1.97E-12	**79**	1.54E-11	**168**	7.69E-14	**112**	1.19E-13	**193**	1.12E-13	204
Total	7.45E-11	**2987**	8.99E-11	**981**	1.22E-12	**1786**	2.29E-13	**372**	1.74E-13	318
2,2,3,3,3-Pentafluoropropan-1-ol										
Delta	6.60E-14	**3**	3.75E-13	**4**	2.29E-15	**3**	2.75E-15	**4**	2.58E-15	**5**
Total	1.79E-12	**72**	2.10E-12	**23**	1.65E-14	**24**	4.70E-15	**8**	4.00E-15	**7**
HFE-254cb1										
Delta	9.07E-13	**36**	5.88E-12	**64**	3.36E-14	**49**	4.41E-14	**71**	4.13E-14	**76**
Total	2.85E-11	**1141**	3.35E-11	**365**	3.33E-13	**487**	7.74E-14	**126**	6.41E-14	**117**
HFE-263fb2										
Delta	4.72E-15	**<1**	2.65E-14	**<1**	1.62E-16	**<1**	1.93E-16	**<1**	1.82E-16	**<1**
Total	1.26E-13	**5**	1.48E-13	**2**	1.13E-15	**2**	3.30E-16	**1**	2.81E-16	**1**
HFE-263m1										
Delta	1.03E-13	**4**	5.87E-13	**6**	3.57E-15	**5**	4.30E-15	**7**	4.04E-15	**7**
Total	2.80E-12	**112**	3.29E-12	**36**	2.61E-14	**38**	7.37E-15	**12**	6.26E-15	**11**
3,3,3-Trifluoropropan-1-ol										
Delta	1.39E-15	**<1**	7.77E-15	**<1**	4.77E-17	**<1**	5.67E-17	**<1**	5.33E-17	**<1**
Total	3.71E-14	**1**	4.35E-14	**<1**	3.32E-16	**<1**	9.69E-17	**<1**	8.27E-17	**<1**
HFE-329mcc2										
Delta	3.22E-12	**129**	4.88E-11	**532**	1.35E-13	**197**	3.66E-13	**593**	4.24E-13	**776**
Total	1.71E-10	**6847**	3.30E-10	**3598**	4.36E-12	**6379**	1.96E-12	**3175**	8.17E-13	**1494**
HFE-338mmz1										
Delta	2.87E-12	**115**	4.22E-11	**460**	1.20E-13	**175**	3.19E-13	**517**	3.63E-13	**663**
Total	1.51E-10	**6053**	2.83E-10	**3081**	3.82E-12	**5584**	1.63E-12	**2644**	6.77E-13	**1238**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
HFE-338mcf2										
Delta	1.96E-12	**79**	1.73E-11	**189**	7.82E-14	**114**	1.35E-13	**219**	1.28E-13	**234**
Total	8.13E-11	**3258**	1.03E-10	**1118**	1.53E-12	**2239**	2.95E-13	**478**	2.00E-13	**365**
Sevoflurane (HFE-347mmz1)										
Delta	6.66E-13	**27**	4.24E-12	**46**	2.45E-14	**36**	3.17E-14	**51**	2.97E-14	**54**
Total	2.05E-11	**821**	2.41E-11	**262**	2.31E-13	**337**	5.54E-14	**90**	4.61E-14	**84**
HFE-347mcc3 (HFE-7000)										
Delta	1.33E-12	**53**	1.01E-11	**110**	5.17E-14	**76**	7.77E-14	**126**	7.29E-14	133
Total	4.91E-11	**1968**	5.88E-11	**641**	7.69E-13	**1125**	1.46E-13	**237**	1.13E-13	207
HFE-347mcf2										
Delta	1.91E-12	**77**	1.60E-11	**175**	7.57E-14	**111**	1.24E-13	**202**	1.18E-13	**215**
Total	7.64E-11	**3063**	9.43E-11	**1028**	1.36E-12	**1993**	2.55E-13	**414**	1.83E-13	**335**
HFE-347pcf2										
Delta	2.08E-12	**83**	1.68E-11	**183**	8.17E-14	**119**	1.30E-13	**211**	1.22E-13	**224**
Total	8.07E-11	**3236**	9.83E-11	**1072**	1.38E-12	**2015**	2.57E-13	**417**	1.90E-13	**348**
HFE-347mmy1										
Delta	1.00E-12	**40**	7.02E-12	**77**	3.82E-14	**56**	5.33E-14	**86**	4.99E-14	**91**
Total	3.42E-11	**1370**	4.04E-11	**440**	4.65E-13	**680**	9.61E-14	**156**	7.76E-14	**142**
HFE-356mec3										
Delta	1.06E-12	**42**	7.47E-12	**81**	4.04E-14	**59**	5.67E-14	**92**	5.32E-14	**97**
Total	3.64E-11	**1457**	4.29E-11	**468**	5.01E-13	**732**	1.03E-13	**166**	8.26E-14	**151**
HFE-356mff2										
Delta	5.90E-14	**2**	3.34E-13	**4**	2.04E-15	**3**	2.45E-15	**4**	2.30E-15	**4**
Total	1.60E-12	**64**	1.87E-12	**20**	1.46E-14	**21**	4.18E-15	**7**	3.56E-15	**7**
HFE-356pcf2										
Delta	1.72E-12	**69**	1.36E-11	**149**	6.72E-14	**98**	1.05E-13	**171**	9.89E-14	**181**
Total	6.57E-11	**2633**	7.96E-11	**867**	1.10E-12	**1601**	2.05E-13	**332**	1.54E-13	**281**
HFE-356pcf3										
Delta	1.25E-12	**50**	8.64E-12	**94**	4.74E-14	**69**	6.54E-14	**106**	6.13E-14	**112**
Total	4.20E-11	**1685**	4.96E-11	**540**	5.58E-13	**816**	1.17E-13	**190**	9.52E-14	**174**
HFE-356pcc3										
Delta	1.13E-12	**45**	7.97E-12	**87**	4.31E-14	**63**	6.05E-14	**98**	5.67E-14	**104**
Total	3.88E-11	**1555**	4.58E-11	**500**	5.34E-13	**781**	1.09E-13	**177**	8.81E-14	**161**
HFE-356mmz1										
Delta	4.79E-14	**2**	2.71E-13	**3**	1.66E-15	**2**	1.98E-15	**3**	1.86E-15	**3**
Total	1.29E-12	**52**	1.52E-12	**17**	1.18E-14	**17**	3.39E-15	**5**	2.89E-15	**5**
HFE-365mcf3										
Delta	3.31E-15	**<1**	1.85E-14	**<1**	1.14E-16	**<1**	1.35E-16	**<1**	1.27E-16	<1
Total	8.84E-14	**4**	1.04E-13	**1**	7.93E-16	**1**	2.31E-16	**<1**	1.97E-16	<1

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
HFE-365mcf2										
Delta	2.01E-13	**8**	1.16E-12	**13**	7.05E-15	**10**	8.53E-15	**14**	8.01E-15	**15**
Total	5.56E-12	**223**	6.52E-12	**71**	5.24E-14	**77**	1.46E-14	**24**	1.24E-14	**23**
HFE-374pc2										
Delta	1.57E-12	**63**	1.20E-11	**130**	6.11E-14	**89**	9.18E-14	**149**	8.62E-14	**158**
Total	5.80E-11	**2326**	6.95E-11	**758**	9.09E-13	**1329**	1.73E-13	**281**	1.34E-13	**245**
4,4,4-Trifluorobutan-1-ol										
Delta	6.72E-17	**<1**	3.76E-16	**<1**	2.31E-18	**<1**	2.74E-18	**<1**	2.58E-18	**<1**
Total	1.80E-15	**<1**	2.11E-15	**<1**	1.61E-17	**<1**	4.68E-18	**<1**	4.00E-18	**<1**
2,2,3,3,4,4,5,5-Octafluorocyclopentanol										
Delta	4.52E-14	**2**	2.56E-13	**3**	1.57E-15	**2**	1.88E-15	**3**	1.76E-15	**3**
Total	1.22E-12	**49**	1.44E-12	**16**	1.12E-14	**16**	3.21E-15	**5**	2.73E-15	**5**
HFE-43-10pccc124 (H-Galden 1040x, HG-11)										
Delta	4.23E-12	**170**	4.92E-11	**536**	1.74E-13	**254**	3.84E-13	**623**	3.90E-13	**713**
Total	2.04E-10	**8176**	3.07E-10	**3353**	4.69E-12	**6854**	1.33E-12	**2156**	6.28E-13	**1149**
HFE-449s1 (HFE-7100)										
Delta	1.08E-12	**43**	8.05E-12	**88**	4.17E-14	**61**	6.17E-14	**100**	5.79E-14	**106**
Total	3.91E-11	**1568**	4.66E-11	**509**	5.95E-13	**870**	1.15E-13	**186**	8.99E-14	**164**
n-HFE-7100										
Delta	1.24E-12	**50**	9.29E-12	**101**	4.82E-14	**70**	7.12E-14	**115**	6.68E-14	**122**
Total	4.52E-11	**1810**	5.38E-11	**587**	6.87E-13	**1004**	1.33E-13	**215**	1.04E-13	**190**
i-HFE-7100										
Delta	1.04E-12	**42**	7.79E-12	**85**	4.04E-14	**59**	5.96E-14	**97**	5.60E-14	**102**
Total	3.78E-11	**1517**	4.51E-11	**492**	5.76E-13	**842**	1.11E-13	**180**	8.70E-14	**159**
HFE-569sf2 (HFE-7200)										
Delta	1.93E-13	**8**	1.13E-12	**12**	6.81E-15	**10**	8.31E-15	**13**	7.80E-15	**14**
Total	5.40E-12	**217**	6.34E-12	**69**	5.20E-14	**76**	1.43E-14	**23**	1.21E-14	**22**
n-HFE-7200										
Delta	2.20E-13	**9**	1.28E-12	**14**	7.74E-15	**11**	9.44E-15	**15**	8.86E-15	16
Total	6.14E-12	**246**	7.21E-12	**79**	5.91E-14	**86**	1.62E-14	**26**	1.37E-14	25
i-HFE-7200										
Delta	1.51E-13	**6**	8.80E-13	**10**	5.31E-15	**8**	6.47E-15	**10**	6.08E-15	**11**
Total	4.21E-12	**169**	4.94E-12	**54**	4.05E-14	**59**	1.11E-14	**18**	9.42E-15	**17**
HFE-236ca12 (HG-10)										
Delta	5.21E-12	**209**	8.31E-11	**907**	2.18E-13	**319**	6.16E-13	**999**	7.39E-13	**1352**
Total	2.81E-10	**11,248**	5.74E-10	**6260**	7.28E-12	**10,646**	3.56E-12	**5769**	1.51E-12	**2769**
HFE-338pcc13 (HG-01)										
Delta	4.50E-12	**181**	5.11E-11	**557**	1.85E-13	**270**	4.00E-13	**648**	4.02E-13	**736**
Total	2.15E-10	**8607**	3.18E-10	**3466**	4.88E-12	**7129**	1.33E-12	**2153**	6.44E-13	**1178**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
1,1,1,3,3,3-Hexafluoropropan-2-ol										
Delta	5.73E-13	**23**	3.57E-12	**39**	2.09E-14	**31**	2.66E-14	**43**	2.50E-14	**46**
Total	1.72E-11	**691**	2.02E-11	**221**	1.87E-13	**274**	4.64E-14	**75**	3.87E-14	**71**
HG-02										
Delta	4.22E-12	**169**	4.79E-11	**523**	1.73E-13	**253**	3.75E-13	**608**	3.77E-13	**690**
Total	2.01E-10	**8072**	2.98E-10	**3250**	4.57E-12	**6686**	1.25E-12	**2019**	6.04E-13	**1105**
HG-03										
Delta	4.42E-12	**177**	5.01E-11	**547**	1.81E-13	**265**	3.92E-13	**636**	3.95E-13	**722**
Total	2.11E-10	**8443**	3.12E-10	**3400**	4.78E-12	**6993**	1.30E-12	**2112**	6.32E-13	**1155**
HG-20										
Delta	5.16E-12	**207**	8.24E-11	**898**	2.16E-13	**316**	6.10E-13	**990**	7.32E-13	**1339**
Total	2.78E-10	**11,143**	5.69E-10	**6201**	7.21E-12	**10,546**	3.52E-12	**5715**	1.50E-12	**2743**
HG-21										
Delta	5.84E-12	**234**	6.79E-11	**740**	2.40E-13	**351**	5.30E-13	**860**	5.38E-13	**984**
Total	2.82E-10	**11,285**	4.24E-10	**4628**	6.47E-12	**9461**	1.84E-12	**2976**	8.67E-13	**1586**
HG-30										
Delta	7.14E-12	**286**	1.14E-10	**1242**	2.99E-13	**437**	8.44E-13	**1369**	1.01E-12	**1852**
Total	3.84E-10	**15,408**	7.86E-10	**8575**	9.98E-12	**14,583**	4.87E-12	**7903**	2.07E-12	**3793**
1-Ethoxy-1,1,2,2,3,3,3-heptafluoropropane										
Delta	2.07E-13	**8**	1.20E-12	**13**	7.28E-15	**11**	8.86E-15	**14**	8.32E-15	15
Total	5.77E-12	**231**	6.77E-12	**74**	5.52E-14	**81**	1.52E-14	**25**	1.29E-14	24
Fluoroxene										
Delta	1.93E-16	**<1**	1.08E-15	**<1**	6.62E-18	**<1**	7.88E-18	**<1**	7.41E-18	**<1**
Total	5.16E-15	**<1**	6.05E-15	**<1**	4.61E-17	**<1**	1.35E-17	**<1**	1.15E-17	**<1**
1,1,2,2-Tetrafluoro-1-(fluoromethoxy)ethane										
Delta	2.01E-12	**80**	1.64E-11	**179**	7.91E-14	**116**	1.27E-13	**206**	1.20E-13	**219**
Total	7.88E-11	**3157**	9.64E-11	**1051**	1.37E-12	**1996**	2.55E-13	**413**	1.87E-13	**341**
2-Ethoxy-3,3,4,4,5-pentafluorotetrahydro-2,5-bis[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]-furan										
Delta	1.86E-13	**7**	1.10E-12	**12**	6.61E-15	**10**	8.12E-15	**13**	7.62E-15	**14**
Total	5.28E-12	**212**	6.19E-12	**68**	5.19E-14	**76**	1.40E-14	**23**	1.18E-14	**22**
Fluoro(methoxy)methane										
Delta	4.44E-14	**2**	2.51E-13	**3**	1.53E-15	**2**	1.83E-15	**3**	1.72E-15	**3**
Total	1.20E-12	**48**	1.40E-12	**15**	1.09E-14	**16**	3.13E-15	**5**	2.67E-15	**5**
Difluoro(methoxy)methane										
Delta	4.79E-13	**19**	2.85E-12	**31**	1.70E-14	**25**	2.10E-14	**34**	1.97E-14	**36**
Total	1.37E-11	**547**	1.60E-11	**175**	1.36E-13	**198**	3.62E-14	**59**	3.06E-14	**56**
Fluoro(fluoromethoxy)methane										
Delta	4.40E-13	**18**	2.59E-12	**28**	1.56E-14	**23**	1.91E-14	**31**	1.79E-14	**33**
Total	1.24E-11	**497**	1.45E-11	**159**	1.21E-13	**176**	3.28E-14	**53**	2.77E-14	**51**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
Difluoro(fluoromethoxy)methane										
Delta	1.75E-12	**70**	1.20E-11	**131**	6.63E-14	**97**	9.05E-14	**147**	8.48E-14	**155**
Total	5.82E-11	**2335**	6.86E-11	**748**	7.55E-13	**1103**	1.62E-13	**262**	1.32E-13	**241**
Trifluoro(fluoromethoxy)methane										
Delta	1.97E-12	**79**	1.44E-11	**157**	7.58E-14	**111**	1.10E-13	**179**	1.03E-13	**189**
Total	7.02E-11	**2812**	8.33E-11	**909**	1.03E-12	**1512**	2.03E-13	**329**	1.61E-13	**294**
HG'-01										
Delta	6.94E-13	**28**	4.36E-12	**48**	2.54E-14	**37**	3.25E-14	**53**	3.05E-14	**56**
Total	2.10E-11	**843**	2.47E-11	**269**	2.31E-13	**338**	5.66E-14	**92**	4.72E-14	**86**
HG'-02										
Delta	7.38E-13	**30**	4.64E-12	**51**	2.70E-14	**39**	3.46E-14	**56**	3.24E-14	59
Total	2.24E-11	**897**	2.63E-11	**287**	2.46E-13	**360**	6.03E-14	**98**	5.03E-14	92
HG'-03										
Delta	6.91E-13	**28**	4.34E-12	**47**	2.53E-14	**37**	3.23E-14	**52**	3.03E-14	**55**
Total	2.09E-11	**840**	2.46E-11	**268**	2.30E-13	**336**	5.64E-14	**91**	4.70E-14	**86**
HFE-329me3										
Delta	3.20E-12	**128**	6.34E-11	**691**	1.35E-13	**198**	4.40E-13	**714**	6.20E-13	**1133**
Total	1.82E-10	**7299**	4.81E-10	**5241**	4.98E-12	**7286**	3.33E-12	**5406**	1.73E-12	**3173**
3,3,4,4, 5,5,6,6,7,7,7-Undecafluoroheptan-1-ol										
Delta	1.52E-15	**<1**	8.51E-15	**<1**	5.22E-17	**<1**	6.21E-17	**<1**	5.84E-17	**<1**
Total	4.06E-14	**2**	4.76E-14	**1**	3.64E-16	**1**	1.06E-16	**<1**	9.04E-17	**<1**
3,3,4,4,5,5,6,6,7,7,8,8,9,9, 9-Pentadecafluorononan-1-ol										
Delta	1.17E-15	**<1**	6.53E-15	**<1**	4.01E-17	**<1**	4.77E-17	**<1**	4.48E-17	**<1**
Total	3.12E-14	**1**	3.65E-14	**<1**	2.80E-16	**<1**	8.14E-17	**<1**	6.95E-17	**<1**
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-Nonadecafluoroundecan-1-ol										
Delta	6.69E-16	**<1**	3.75E-15	**<1**	2.30E-17	**<1**	2.73E-17	**<1**	2.57E-17	**<1**
Total	1.79E-14	**1**	2.10E-14	**<1**	1.60E-16	**<1**	4.67E-17	**<1**	3.98E-17	**<1**
2-Chloro-1,1,2-trifluoro-1-methoxyethane										
Delta	3.99E-13	**16**	2.41E-12	**26**	1.43E-14	**21**	1.79E-14	**29**	1.68E-14	**31**
Total	1.16E-11	**465**	1.36E-11	**149**	1.19E-13	**174**	3.09E-14	**50**	2.60E-14	**48**
PFPMIE (perfluoropolymethylisopropyl ether)										
Delta	3.04E-12	**122**	9.93E-11	**1083**	1.30E-13	**191**	5.60E-13	**908**	1.23E-12	**2247**
Total	1.90E-10	**7619**	9.89E-10	**10,789**	5.65E-12	**8263**	6.67E-12	**10,815**	7.38E-12	**13,501**
HFE-216										
Delta	7.45E-16	**<1**	4.17E-15	**<1**	2.56E-17	**<1**	3.04E-17	**<1**	2.86E-17	**<1**
Total	1.99E-14	**1**	2.34E-14	**<1**	1.78E-16	**<1**	5.20E-17	**<1**	4.44E-17	**<1**
Trifluoromethyl formate										
Delta	1.65E-12	**66**	1.14E-11	**124**	6.24E-14	**91**	8.62E-14	**140**	8.08E-14	**148**
Total	5.54E-11	**2220**	6.53E-11	**712**	7.36E-13	**1075**	1.55E-13	**251**	1.25E-13	229

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
Perfluoroethyl formate										
Delta	1.62E-12	**65**	1.12E-11	**122**	6.16E-14	**90**	8.50E-14	**138**	7.97E-14	**146**
Total	5.46E-11	**2190**	6.44E-11	**703**	7.26E-13	**1061**	1.53E-13	**247**	1.24E-13	**226**
Perfluoropropyl formate										
Delta	1.13E-12	**45**	7.34E-12	**80**	4.18E-14	**61**	5.51E-14	**89**	5.16E-14	**94**
Total	3.56E-11	**1427**	4.18E-11	**456**	4.22E-13	**616**	9.70E-14	**157**	8.01E-14	**147**
Perfluorobutyl formate										
Delta	1.14E-12	**46**	7.62E-12	**83**	4.27E-14	**62**	5.74E-14	**93**	5.38E-14	**98**
Total	3.70E-11	**1485**	4.36E-11	**475**	4.62E-13	**675**	1.02E-13	**165**	8.36E-14	**153**
2,2,2-Trifluoroethyl formate										
Delta	1.16E-13	**5**	6.66E-13	**7**	4.06E-15	**6**	4.88E-15	**8**	4.59E-15	**8**
Total	3.18E-12	**128**	3.73E-12	**41**	2.96E-14	**43**	8.36E-15	**14**	7.11E-15	**13**
3,3,3-Trifluoropropyl formate										
Delta	6.12E-14	**2**	3.47E-13	**4**	2.12E-15	**3**	2.54E-15	**4**	2.39E-15	**4**
Total	1.66E-12	**66**	1.94E-12	**21**	1.52E-14	**22**	4.34E-15	**7**	3.70E-15	7
1,2,2,2-Tetrafluoroethyl formate										
Delta	1.35E-12	**54**	9.12E-12	**99**	5.07E-14	**74**	6.89E-14	**112**	6.45E-14	**118**
Total	4.44E-11	**1778**	5.22E-11	**569**	5.67E-13	**829**	1.23E-13	**199**	1.00E-13	**183**
1,1,1,3,3,3-Hexafluoropropan-2-yl formate										
Delta	9.53E-13	**38**	6.46E-12	**70**	3.59E-14	**52**	4.88E-14	**79**	4.57E-14	**84**
Total	3.14E-11	**1259**	3.70E-11	**403**	4.02E-13	**587**	8.69E-14	**141**	7.10E-14	**130**
Perfluorobutyl acetate										
Delta	5.90E-15	**<1**	3.31E-14	**<1**	2.03E-16	**<1**	2.41E-16	**<1**	2.27E-16	**<1**
Total	1.58E-13	**6**	1.85E-13	**2**	1.42E-15	**2**	4.12E-16	**1**	3.52E-16	**1**
Perfluoropropyl acetate										
Delta	6.17E-15	**<1**	3.46E-14	**<1**	2.12E-16	**<1**	2.52E-16	**<1**	2.37E-16	**<1**
Total	1.65E-13	**7**	1.93E-13	**2**	1.48E-15	**2**	4.31E-16	**1**	3.67E-16	**1**
Perfluoroethyl acetate										
Delta	7.34E-15	**<1**	4.11E-14	**<1**	2.52E-16	**<1**	3.00E-16	**<1**	2.82E-16	**1**
Total	1.96E-13	**8**	2.30E-13	**3**	1.76E-15	**3**	5.12E-16	**1**	4.37E-16	1
Trifluoromethyl acetate										
Delta	7.39E-15	**<1**	4.14E-14	**<1**	2.54E-16	**<1**	3.02E-16	**<1**	2.84E-16	**1**
Total	1.97E-13	**8**	2.32E-13	**3**	1.77E-15	**3**	5.16E-16	**1**	4.40E-16	**1**
Methyl carbonofluoridate										
Delta	3.02E-13	**12**	1.88E-12	**20**	1.10E-14	**16**	1.40E-14	**23**	1.31E-14	**24**
Total	9.05E-12	**363**	1.06E-11	**116**	9.70E-14	**142**	2.43E-14	**39**	2.03E-14	**37**
1,1-Difluoroethyl carbonofluoridate										
Delta	9.41E-14	**4**	5.35E-13	**6**	3.26E-15	**5**	3.92E-15	**6**	3.68E-15	**7**
Total	2.55E-12	**102**	2.99E-12	**33**	2.35E-14	**34**	6.70E-15	**11**	5.70E-15	**10**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
1,1-Difluoroethyl 2,2,2-trifluoroacetate										
Delta	1.08E-13	**4**	6.15E-13	**7**	3.75E-15	**5**	4.50E-15	**7**	4.23E-15	**8**
Total	2.94E-12	**118**	3.44E-12	**38**	2.70E-14	**40**	7.70E-15	**12**	6.55E-15	**12**
Ethyl 2,2,2-trifluoroacetate										
Delta	4.88E-15	**<1**	2.74E-14	**<1**	1.68E-16	**<1**	2.00E-16	**<1**	1.88E-16	**<1**
Total	1.31E-13	**5**	1.53E-13	**2**	1.17E-15	**2**	3.41E-16	**1**	2.91E-16	1
2,2,2-Trifluoroethyl 2,2,2-trifluoroacetate										
Delta	2.43E-14	**1**	1.37E-13	**1**	8.37E-16	**1**	9.98E-16	**2**	9.38E-16	**2**
Total	6.52E-13	**26**	7.64E-13	**8**	5.90E-15	**9**	1.70E-15	**3**	1.45E-15	**3**
Methyl 2,2,2-trifluoroacetate										
Delta	1.80E-13	**7**	1.04E-12	**11**	6.32E-15	**9**	7.65E-15	**12**	7.18E-15	**13**
Total	4.98E-12	**200**	5.84E-12	**64**	4.71E-14	**69**	1.31E-14	**21**	1.11E-14	**20**
Methyl 2,2-difluoroacetate										
Delta	1.16E-14	**0**	6.54E-14	**1**	4.01E-16	**1**	4.77E-16	**1**	4.49E-16	**1**
Total	3.12E-13	**12**	3.66E-13	**4**	2.81E-15	**4**	8.15E-16	**1**	6.95E-16	**1**
Difluoromethyl 2,2,2-trifluoroacetate										
Delta	9.52E-14	**4**	5.40E-13	**6**	3.30E-15	**5**	3.95E-15	**6**	3.71E-15	**7**
Total	2.58E-12	**103**	3.02E-12	**33**	2.37E-14	**35**	6.76E-15	**11**	5.75E-15	**11**
2,2,3,3,4,4,4-Heptafluorobutan-1-ol										
Delta	1.17E-13	**5**	6.72E-13	**7**	4.08E-15	**6**	4.93E-15	**8**	4.63E-15	**8**
Total	3.21E-12	**129**	3.77E-12	**41**	3.02E-14	**44**	8.45E-15	**14**	7.18E-15	13
1,1,2-Trifluoro-2-(trifluoromethoxy)-ethane										
Delta	2.27E-12	**91**	2.26E-11	**246**	9.20E-14	**134**	1.77E-13	**287**	1.72E-13	**314**
Total	1.01E-10	**4063**	1.37E-10	**1489**	2.12E-12	**3096**	4.65E-13	**754**	2.69E-13	**492**
1-Ethoxy-1,1,2,3,3,3-hexafluoropropane										
Delta	8.16E-14	**3**	4.66E-13	**5**	2.84E-15	**4**	3.41E-15	**6**	3.20E-15	**6**
Total	2.22E-12	**89**	2.61E-12	**28**	2.06E-14	**30**	5.84E-15	**9**	4.96E-15	**9**
1,1,1,2,2,3,3-Heptafluoro-3-(1,2,2,2-tetrafluoroethoxy)-propane										
Delta	3.40E-12	**136**	8.11E-11	**884**	1.45E-13	**212**	5.26E-13	**853**	8.65E-13	**1582**
Total	2.01E-10	**8075**	6.76E-10	**7371**	5.71E-12	**8353**	4.82E-12	**7812**	3.26E-12	**5960**
2,2,3,3-Tetrafluoro-1-propanol										
Delta	4.58E-14	**2**	2.59E-13	**3**	1.59E-15	**2**	1.90E-15	**3**	1.78E-15	**3**
Total	1.24E-12	**50**	1.45E-12	**16**	1.13E-14	**17**	3.24E-15	**5**	2.76E-15	**5**
2,2,3,4,4,4-Hexafluoro-1-butanol										
Delta	6.00E-14	**2**	3.40E-13	**4**	2.07E-15	**3**	2.48E-15	**4**	2.33E-15	**4**
Total	1.62E-12	**65**	1.90E-12	**21**	1.48E-14	**22**	4.25E-15	**7**	3.62E-15	7
2,2,3,3,4,4,4-Heptafluoro-1-butanol										
Delta	5.72E-14	**2**	3.25E-13	**4**	1.98E-15	**3**	2.38E-15	**4**	2.23E-15	**4**
Total	1.55E-12	**62**	1.82E-12	**20**	1.43E-14	**21**	4.07E-15	**7**	3.46E-15	**6**

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Table 8.SM.16 (continued)

Acronym, Common Name or Chemical Name	AGWP 20-year (W m^{-2} yr kg^{-1})	GWP 20-year	AGWP 100-year (W m^{-2} yr kg^{-1})	GWP 100-year	AGTP 20-year (K kg^{-1})	GTP 20-year	AGTP 50-year (K kg^{-1})	GTP 50-year	AGTP 100-year (K kg^{-1})	GTP 100-year
1,1,2,2-Tetrafluoro-3-methoxy-propane										
Delta	1.87E-15	**<1**	1.05E-14	**<1**	6.43E-17	**<1**	7.65E-17	**<1**	7.19E-17	**<1**
Total	5.00E-14	**2**	5.86E-14	**1**	4.48E-16	**1**	1.31E-16	**<1**	1.11E-16	**<1**
Perfluoro-2-methyl-3-pentanone										
Delta	3.55E-16	**<1**	1.99E-15	**<1**	1.22E-17	**<1**	1.45E-17	**<1**	1.36E-17	**<1**
Total	9.49E-15	**<1**	1.11E-14	**<1**	8.49E-17	**<1**	2.48E-17	**<1**	2.11E-17	**<1**
3,3,3-Trifluoro-propanal										
Delta	3.83E-17	**<1**	2.14E-16	**<1**	1.31E-18	**<1**	1.56E-18	**<1**	1.47E-18	**<1**
Total	1.02E-15	**<1**	1.20E-15	**<1**	9.15E-18	**<1**	2.67E-18	**<1**	2.28E-18	**<1**
2-Fluoroethanol										
Delta	3.14E-15	**<1**	1.76E-14	**<1**	1.08E-16	**<1**	1.28E-16	**<1**	1.21E-16	**<1**
Total	8.39E-14	**3**	9.83E-14	**1**	7.53E-16	**1**	2.19E-16	**<1**	1.87E-16	<1
2,2-Difluoroethanol										
Delta	1.08E-14	**<1**	6.05E-14	**1**	3.71E-16	**1**	4.42E-16	**1**	4.15E-16	**1**
Total	2.88E-13	**12**	3.38E-13	**4**	2.60E-15	**4**	7.54E-16	**1**	6.43E-16	**1**
2,2,2-Trifluoroethanol										
Delta	7.01E-14	3	3.98E-13	4	2.43E-15	4	2.91E-15	5	2.74E-15	**5**
Total	1.90E-12	**76**	2.23E-12	**24**	1.75E-14	**26**	4.98E-15	**8**	4.24E-15	**8**
1,1′-Oxybis[2-(difluoromethoxy)-1,1,2,2-tetrafluoroethane										
Delta	4.65E-12	**186**	7.57E-11	**825**	1.95E-13	**285**	5.58E-13	**905**	6.78E-13	**1240**
Total	2.52E-10	**10,096**	5.27E-10	**5741**	6.57E-12	**9609**	3.31E-12	**5367**	1.42E-12	**2603**
1,1,3,3,4,4,6,6,7,7,9,9,10,10,12,12-hexadecafluoro-2,5,8,11-Tetraoxadodecane										
Delta	4.25E-12	**170**	6.91E-11	**754**	1.78E-13	**260**	5.10E-13	**827**	6.20E-13	**1133**
Total	2.30E-10	**9223**	4.81E-10	**5245**	6.00E-12	**8778**	3.02E-12	**4903**	1.30E-12	**2378**
1,1,3,3,4,4,6,6,7,7,9,9,10,10,12,12,13,13,15,15-Eicosafluoro-2,5,8,11,14-Pentaoxapentadecane										
Delta	3.43E-12	**138**	5.59E-11	**609**	1.44E-13	**211**	4.12E-13	**668**	5.01E-13	**916**
Total	1.86E-10	**7456**	3.89E-10	**4240**	4.85E-12	**7095**	2.44E-12	**3963**	1.05E-12	**1923**

8.SM.16 Metric Values to Support Figure 8.32 and Figure 8.33

Table 8.SM.17 | Metric values used for Figures 8.32 and 8.33.

Species	GWP_{10}	GWP_{20}	GWP_{50}	GWP_{100}	GTP_{10}	GTP_{20}	GTP_{50}	GTP_{100}
CO_2	1	1	1	1	1	1	1	1
CH_4	104.2	83.9	48.4	28.5	99.9	67.5	14.1	4.3
N_2O	246.6	263.7	275.6	264.8	253.5	276.9	281.8	234.2
BC	4349.2	2421.1	1139.3	658.6	2398.2	702.8	110.0	90.7
OC	–438.5	–244.1	–114.9	–66.4	–241.8	–70.9	–11.1	–9.1
SO_2	–253.5	–141.1	–66.4	–38.4	–139.6	–40.9	–6.4	–5.3
NOx	134.2	16.7	–15.6	–10.8	2.8	–86.3	–27.4	–2.8
CO	8.6	5.9	3.2	1.9	6.8	3.7	0.7	0.3

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8.SM.17 Metric Values for Sectors to Support Section 8.7.2

Table 8.SM.18 | GWPs and GTPs for NO_X, BC, OC and SO_2 from various sectors (metrics for SO_2 are given on SO_2 basis, while for NO_X they are given on a nitrogen basis). For the reference gas CO_2, RE and IRF from AR4 are used in the calculations. The GWP_{100} and GTP_{100} values can be scaled by 0.94 and 0.92, respectively, to account for updated values for the reference gas CO_2. For 20 years the changes are negligible. ari is aerosol–radiation interaction.

Sector and emission region (if sub-global)	GWP		GTP	
	H = 20	H = 100	H = 20	H = 100
Aviation				
NO_X[a]	92 to 338	–21 to 67	–396 to –121	–5.8 to 7.9
NO_X[b]	120 to 470	–2.1 to 71	–590 to –200	–9.5 to 7.6
NO_X[h]	415	75	–239	8.6
Shipping				
NO_X[b]	–76 to –31	–36 to –25	–190 to –130	–6.1 to –4.2
NO_X[c]	–107	–73	–135	
SO_2[b]	–150 to –37	–43 to –11	–44 to –11	–6.1 to –1.5
SO_2, Arctic[e]	–47	–13		
OC, Arctic[e]	–151	–43		
BC ari, Arctic[e]	2037	579		
BC on snow, Arctic[e]	764	217		
Energy Related				
BC ari + albedo[g]	2,800 ± 1,800	790 ± 530		
OC Energy related[g]	–110 (–40,–210)	–30 (–12, –60)		
Industry/Power BC, Asia[f]	3,260	910		
Household BC, Asia[f]	2,680	750		
Transport BC, Asia[f]	2,640	740		
Transport BC, North America[f]	3,900	1,090		
Household OC, Asia[f]	–260	–72		
Transport OC, Asia[f]	–180	–50		
Industry/Power SO_2, Asia[f]	–106 (ari)	–30 (ari)		
Industry/Power SO_2, North America[f]	–215 (ari)	–60 (ari)		
Coal-fired power, NO_X[d]	20			
Coal-fired power, SO_2[d]	–189 (ari)	–53 (ari)		
Petroleum Production				
BC ari, Arctic	2,369	673		
BC on snow, Arctic[e]	4,104	1,166		
SO_2, Arctic[e]	–64	–18		
OC, Arctic[e]	–152	–43		
Open Biomass				
BC ari + albedo[g]	3,100 ± 1,300	880 ± 370		
OC[g]	–180 (–70, –360)	–53 (–20, –100)		

Notes:

[a] Myhre et al. (2011)

[b] Fuglestvedt et al. (2010)

[c] Collins et al. (2010)

[d] Shindell and Faluvegi (2010)

[e] Ødemark et al. (2012)

[f] Shindell et al. (2008)

[g] Bond et al. (2011)

[h] Köhler et al. (2013)

8.SM.18 Further Information on Temperature Impact from Various Sectors to Support Section 8.7.2

Table 8.SM.19 | Information about emissions and metric values used in calculations of temperature impacts of sectors.

Species	Global Emissions (Gg)	AGTP Values Based on	GTP_{20}	GTP_{100}
CO_2	3.69E+07	Joos et al. (2013) and AR5	1	1
CH_4	3.64E+05	Updated by AR5	67	4.3
N_2O	1.07E+04	Updated by AR5	277	234
HCFC-141b	7.68E-01	Updated by AR5	1853	111
HCF-142b	6.18E+00	Updated by AR5	4393	356
HFC-23	1.75E+01	Updated by AR5	11524	12709
HFC-32	2.36E+00	Updated by AR5	1362	94
HFC-125	3.00E+01	Updated by AR5	5797	967
HFC-134a	1.63E+02	Updated by AR5	3053	201
HFC-143a	3.25E+01	Updated by AR5	6957	2505
HFC-152a	2.79E+01	Updated by AR5	174	19
HFC-227ea	7.18E+00	Updated by AR5	5283	1500
HFC-236fa	1.59E-01	Updated by AR5	7397	8377
HFC-245fa	4.11E+00	Updated by AR5	1974	121
HFC-365mfc	1.73E+00	Updated by AR5	1893	114
HFC-43-10mee	2.69E-01	Updated by AR5	3718	281
SF_6	6.50E+00	Updated by AR5	18904	28215
NF_3	1.75E-01	Updated by AR5	13723	18119
PFC-14	1.12E+01	Updated by AR5	5272	8038
PFC-116	2.43E+00	Updated by AR5	8877	13456
PFC-218	4.13E-01	Updated by AR5	7176	10654
PFC-318	2.49E-02	Updated by AR5	7676	11456
PFC-3-1-10	1.96E-02	Updated by AR5	7419	11016
PFC-4-1-12	9.58E-06	Updated by AR5	6856	10284
PFC-5-1-14	3.78E-01	Updated by AR5	6365	9493
BC	5.31E+03	Bond et al. (2013) aerosol radiation interaction and albedo effect included in metric values	703	91
OC	1.36E+04	Fuglestvedt et al. (2010)	–71	–9.1
SO_2	1.27E+05 (in SO_2)	Fuglestvedt et al. (2010)	–41	–5.3
Contrails and CIC		Updated by AR5	0.75	0.10
Aircraft NO_x		Stevenson et al. (2004), as given by Fuglestvedt et al. (2010)	–204	6.7
Shipping NO_x		Fuglestvedt et al. (2008), as given by Fuglestvedt et al. (2010)	–162	–4.0
Surface NO_x	3.72E+04 (includes shipping and air, in N)	The global run in Wild et al. (2001), as given by Fuglestvedt et al. (2010)	–86	–2.8
CO	8.93E+05	Derwent et al. (2001), as given by Fuglestvedt et al. (2010)	3.7	0.27
VOC	1.60E+05	Collins et al. (2002) , as given Fuglestvedt et al. (2010)	7.4	0.61
NH_3	4.93E+04	Shindell et al. (2009)	–23	–3.0
ACI		(–0.45)/(–0.4)*SO_2, updated by AR5	–46	–5.9

AGTPs for the aerosols OC and SO_2 are from Fuglestvedt et al. (2010). For BC, the metric parameterization is based on Bond et al. (2013); the RF of the aerosol radiation interaction (0.71 W m^{-2}) and snow and ice albedo effects (0.1 + 0.03 W m^{-2}).

The parameters for the ozone precursors NO_x is from the global run in Wild et al. (2001), CO from Derwent et al. (2001) and VOC from Collins et al. (2002), as given by Fuglestvedt et al. (2010). For NO_x emissions from shipping and aircraft, the parameters are from Fuglestvedt et al. (2008) and Wild et al. (2001), respectively, as given by Fuglestvedt et al. (2010).

The parameters for the indirect effect of contrails and contrail induced cirrus (CIC) are updated for AR5. The lifetime is set to 5 hours, as in Fuglestvedt et al. (2010), while the REs are based on a radiative forcing of 10 m W m^{-2} and 50 m W m^{-2} for contrails and the sum of contrails and CIC, respectively. The calculations are based emissions from aviation of about 776 Tg(CO_2), which comes from EDGAR 2008 (http://edgar.jrc.ec.europa.eu/overview.php?v=42).

The aerosol–cloud interaction has been calculated with a scaling relative to the direct effect of sulphate. The scaling is –0.45 / –0.4 = 1.125 and is used across almost all sectors (i.e., no separate scaling used for aerosol–cloud interaction for shipping). We do not account for any aerosol–cloud interaction from the aviation sector, as we include the impact of contrails and CIC.

We have tested the effect of various aerosol–cloud interaction values and attributions to components (e.g., attributing aerosol–cloud interaction equally to OC and sulphate, setting the aerosol–cloud interaction at the maximum or minimum of its 90% confidence interval, choosing a larger BC forcing, etc.). The ranking of sectors for global emissions differs little between the different parameterizations and mostly for the shortest time horizons.

The calculations presented here do not include the climate–carbon feedback for non-CO_2 emissions, which can substantially increase those values (Collins et al., 2013). Emissions: Emission Database for Global Atmospheric Research (EDGAR) 2008 (http://edgar.jrc.ec.europa.eu/overview.php?v=42). VOC emissions are converted to carbon mass units based on IPCC (2006). BC and OC emissions for year 2005 are taken from Shindell et al. (2012). Emission data requires frequently updates when new information become available (e.g., Lam et al., (2012). BC and OC emission from biomass burning are taken from Lamarque et al. (2010).

Figure 8.34 is based on the calculations and data described above. Figure 8.SM.9 shows the net temperature responses as function of time for one year pulse emissions. Figure 8.SM.10 shows the net temperature responses as function of time assuming constant emissions from the various sectors.

Figures 8.32 and 8.33 are based on the emission data given above for CO_2, CH_4, N_2O, BC, OC, SO_2, NO_x and CO. The following metric values used are given in Table 8.SM.18.

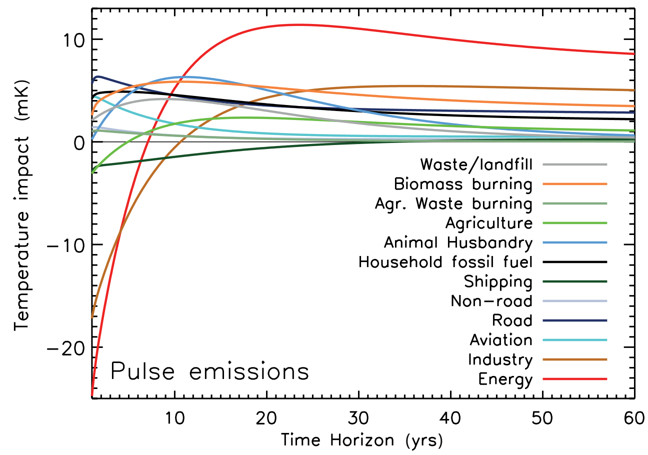

Figure 8.SM.9 | Temperature responses from the various sectors as function of time for 1-year pulse emissions.

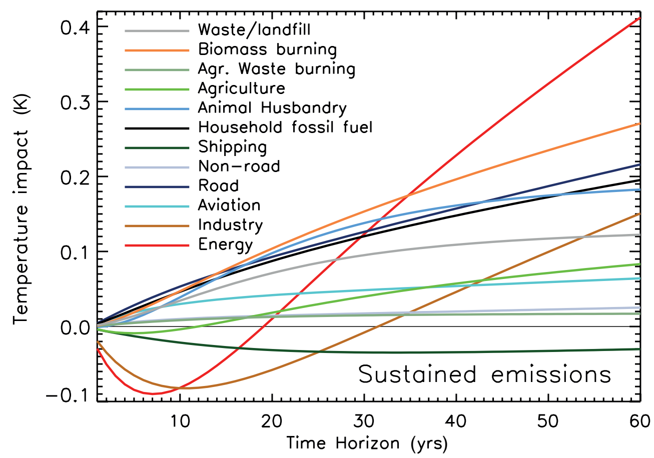

Figure 8.SM.10 | Temperature responses from the various sectors as function of time, assuming constant emissions.

References

Baliunas, S., and R. Jastrow, 1990: Evidence for long-term brightness changes of solar-type stars. *Nature*, **348**, 520–523.

Ball, W., Y. Unruh, N. Krivova, S. Solanki, T. Wenzler, D. Mortlock, and A. Jaffe, 2012: Reconstruction of total solar irradiance 1974–2009. *Astron. Astrophys.*, **541**, A27.

Bond, T., C. Zarzycki, M. Flanner, and D. Koch, 2011: Quantifying immediate radiative forcing by black carbon and organic matter with the Specific Forcing Pulse. *Atmos. Chem. Phys.*, **11**, 1505–1525.

Bond, T. C., et al., 2013: Bounding the role of black carbon in the climate system: A scientific assessment. *J. Geophys. Res. Atmos.*, **118**, 5380–5552.

Boucher, O., and M. Reddy, 2008: Climate trade-off between black carbon and carbon dioxide emissions. *Energ. Policy*, **36**, 193–200.

Boucher, O., P. Friedlingstein, B. Collins, and K. P. Shine, 2009: The indirect global warming potential and global temperature change potential due to methane oxidation. *Environ. Res. Lett.*, **4**, 044007.

Butler, J., B. Johnson, J. Rice, E. Shirley, and R. Barnes, 2008: Sources of differences in on-Orbital total solar irradiance measurements and description of a proposed laboratory intercomparison. *J. Res. Natl. Inst. Stand. Technol.*, **113**, 187–203.

Caldeira, K., and J. Kasting, 1993: Insensitivity of global warming potentials to carbon-dioxide emission scenarios. *Nature*, **366**, 251–253.

Clette, F., D. Berghmans, P. Vanlommel, R. Van der Linden, A. Koeckelenbergh, and L. Wauters, 2007: From the Wolf number to the International Sunspot Index: 25 years of SIDC. *Adv. Space Res.*, **40**, 919–928.

Collins, W., R. Derwent, C. Johnson, and D. Stevenson, 2002: The oxidation of organic compounds in the troposphere and their global warming potentials. *Clim. Change*, **52**, 453–479.

Collins, W. J., S. Sitch, and O. Boucher, 2010: How vegetation impacts affect climate metrics for ozone precursors. *J. Geophys. Res. Atmos.*, **115**, D23308.

Collins, W. J., M. M. Fry, H. Yu, J. S. Fuglestvedt, D. T. Shindell, and J. J. West, 2013: Global and regional temperature-change potentials for near-term climate forcers. *Atmos. Chem. Phys.*, **13**, 2471–2485.

Crowley, T. J., and M. B. Unterman, 2013: Technical details concerning development of a 1200-yr proxy index for global volcanism. *Earth Syst. Sci. Data*, **5**, 187–197.

Daniel, J., E. Fleming, R. Portmann, G. Velders, C. Jackman, and A. Ravishankara, 2010: Options to accelerate ozone recovery: Ozone and climate benefits. *Atmos. Chem. Phys.*, **10**, 7697–7707.

DeLand, M., and R. Cebula, 2012: Solar UV variations during the decline of Cycle 23. *J. Atmos. Sol. Terres. Phys.*, **77**, 225–234.

Derwent, R., W. Collins, C. Johnson, and D. Stevenson, 2001: Transient behaviour of tropospheric ozone precursors in a global 3-D CTM and their indirect greenhouse effects. *Clim. Change*, **49**, 463–487.

Enting, I. G., T. M. L. Wigley, and M. Heimann, 1994: *Future Emissions and Concentrations of Carbon Dioxide: Key Ocean/Atmosphere/Land Analyses.* CSIRO Division of Atmospheric Research Technical Paper no. 31.

Feulner, G., 2011: Are the most recent estimates for Maunder Minimum solar irradiance in agreement with temperature reconstructions? *Geophys. Res. Lett.*, **38**, L16706.

Fontenla, J., O. White, P. Fox, E. Avrett, and R. Kurucz, 1999: Calculation of solar irradiances. I. Synthesis of the solar spectrum. *Astrophys. J.*, **518**, 480–499.

Forster, P., et al., 2005: Resolution of the uncertainties in the radiative forcing of HFC-134a. *J. Quant. Spectrosc. Radiat. Transfer*, **93**, 447–460.

Forster, P., et al., 2007: Changes in atmospheric constituents and in radiative forcing. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 129–234.

Foukal, P., A. Ortiz, and R. Schnerr, 2011: Dimming of the 17th century sun. *Astrophys. J. Letters*, **733**, L38.

Fox, N., et al., 2011: Accurate radiometry from space: an essential tool for climate studies. *Philos. Trans. R. Soc. A*, **369**, 4028–4063.

Freckleton, R., E. Highwood, K. Shine, O. Wild, K. Law, and M. Sanderson, 1998: Greenhouse gas radiative forcing: Effects of averaging and inhomogeneities in trace gas distribution. *Q. J. R. Meteorol. Soc.*, **124**, 2099–2127.

Frohlich, C., 2009: Evidence of a long-term trend in total solar irradiance. *Astron. Astrophys.*, **501**, L27–U508.

Fuglestvedt, J., T. Berntsen, G. Myhre, K. Rypdal, and R. Skeie, 2008: Climate forcing from the transport sectors. *Proc. Natl. Acad. Sci. U.S.A.*, **105**, 454–458.

Fuglestvedt, J. S., et al., 2010: Transport impacts on atmosphere and climate: Metrics. *Atmos. Environ.*, **44**, 4648–4677.

Gao, C., A. Robock, and C. Ammann, 2008: Volcanic forcing of climate over the past 1500 years: An improved ice core-based index for climate models. *J. Geophys. Res. Atmos.*, **113**, D23111.

Gray, L., et al., 2010: Solar influences on climate. *Rev. Geophys.*, **48**, RG4001.

Haigh, J., A. Winning, R. Toumi, and J. Harder, 2010: An influence of solar spectral variations on radiative forcing of climate. *Nature*, **467**, 696–699.

Hall, J., and G. Lockwood, 2004: The chromospheric activity and variability of cycling and flat activity solar-analog stars. *Astrophys. J.*, **614**, 942–946.

Hansen, J., M. Sato, P. Kharecha, and K. von Schuckmann, 2011: Earth's energy imbalance and implications. *Atmos. Chem. Phys.*, **11**, 13421–13449.

Harder, J., J. Fontenla, P. Pilewskie, E. Richard, and T. Woods, 2009: Trends in solar spectral irradiance variability in the visible and infrared. *Geophys. Res. Lett.*, **36**, L07801.

Hathaway, D., R. Wilson, and E. Reichmann, 2002: Group sunspot numbers: Sunspot cycle characteristics. *Sol. Phys.*, **211**, 357–370.

Holmes, C. D., M. J. Prather, O. A. Søvde, and G. Myhre, 2013: Future methane, hydroxyl, and their uncertainties: Key climate and emission parameters for future predictions. *Atmos. Chem. Phys.*, **13**, 285–302.

Hoyt, D., and K. Schatten, 1998: Group Sunspot Numbers: A new solar activity reconstruction. *Sol. Phys.*, **179**, 189–219.

IPCC, 2006: *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme.

Jacquinet-Husson, N., et al., 2011: The 2009 edition of the GEISA spectroscopic database. *J. Quant. Spectrosc. Radiat. Transfer*, **112**, 2395–2445.

Jain, A. K., B. P. Briegleb, K. Minschwaner, and D. J. Wuebbles, 2000: Radiative forcings and global warming potentials of 39 greenhouse gases. *J. Geophys. Res. Atmos.*, **105**, 20773–20790.

Joos, F., M. Bruno, R. Fink, U. Siegenthaler, T. Stocker, and C. LeQuere, 1996: An efficient and accurate representation of complex oceanic and biospheric models of anthropogenic carbon uptake. *Tellus B*, **48**, 397–417.

Joos, F., et al., 2013: Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: A multi-model analysis. *Atmos. Chem. Phys.*, **13**, 2793–2825.

Judge, P., G. Lockwood, R. Radick, G. Henry, A. Shapiro, W. Schmutz, and C. Lindsey, 2012: Confronting a solar irradiance reconstruction with solar and stellar data (Research Note). *Astron. Astrophys.*, **544**, A88.

Koehler, M. O., G. Raedel, K. P. Shine, H. L. Rogers, and J. A. Pyle, 2013: Latitudinal variation of the effect of aviation NOx emissions on atmospheric ozone and methane and related climate metrics. *Atmos. Environ.*, **64**, 1–9.

Krivova, N., L. Vieira, and S. Solanki, 2010: Reconstruction of solar spectral irradiance since the Maunder minimum. *J. Geophys. Res. Space Phys.*, **115**, A12112.

Lam, N. L., et al., 2012: Household light makes global heat: High black carbon emissions from kerosene wick lamps. *Environ. Sci. Technol.*, **46**, 13531–13538.

Lamarque, J., et al., 2010: Historical (1850–2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: Methodology and application. *Atmos. Chem. Phys.*, **10**, 7017–7039.

Lean, J., and M. Deland, 2012: How does the sun's spectrum vary? *J. Clim.*, **25**, 2555–2560.

Lee, Y. H., et al., 2013: Evaluation of preindustrial to present-day black carbon and its albedo forcing from Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP). *Atmos. Chem. Phys.*, **13**, 2607–2634.

Li, S., and A. Jarvis, 2009: Long run surface temperature dynamics of an A-OGCM: The HadCM3 4xCO_2 forcing experiment revisited. *Clim. Dyn.*, **33**, 817–825.

Lockwood, M., and M. Owens, 2011: Centennial changes in the heliospheric magnetic field and open solar flux: The consensus view from geomagnetic data and cosmogenic isotopes and its implications. *J. Geophys. Res. Space Phys.*, **116**, A04109.

Morgan, M. G., and M. Henrion, 1990: *A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.

Myhre, G., and F. Stordal, 1997: Role of spatial and temporal variations in the computation of radiative forcing and GWP. *J. Geophys. Res. Atmos.*, **102**, 11181–11200.

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

Myhre, G., F. Stordal, I. Gausemel, C. J. Nielsen, and E. Mahieu, 2006: Line-by-line calculations of thermal infrared radiation representative for global condition: CFC-12 as an example. *J. Quant. Spectrosc. Radiat. Transfer*, **97**, 317–331.

Myhre, G., et al., 2011: Radiative forcing due to changes in ozone and methane caused by the transport sector. *Atmos. Environ.*, **45**, 387–394.

Naik, V., A. K. Jain, K. O. Patten, and D. J. Wuebbles, 2000: Consistent sets of atmospheric lifetimes and radiative forcings on climate for CFC replacements: HCFCs and HFCs. *J. Geophys. Res. Atmos.*, **105**, 6903–6914.

Ødemark, K., S. B. Dalsoren, B. H. Samset, T. K. Berntsen, J. S. Fuglestvedt, and G. Myhre, 2012: Short-lived climate forcers from current shipping and petroleum activities in the Arctic. *Atmos. Chem. Phys.*, **12**, 1979–1993.

Olivié, D. J. L., G. Peters, and D. Saint-Martin, 2012: Atmosphere response time scales estimated from AOGCM Experiments. *J. Clim.*, **25**, 7956–7972.

Pinnock, S., M. D. Hurley, K. P. Shine, T. J. Wallington, and T. J. Smyth, 1995: Radiative forcing of climate by hydrochlorofluorocarbons and hydrofluorocarbons. *J. Geophys. Res. Atmos.*, **100**, 23227–23238.

Plattner, G. K., et al., 2008: Long-term climate commitments projected with climate-carbon cycle models. *J. Clim.*, **21**, 2721–2751.

Pongratz, J., T. Raddatz, C. H. Reick, M. Esch, and M. Claussen, 2009: Radiative forcing from anthropogenic land cover change since AD 800. *Geophys. Res. Lett.*, **36**, L02709.

Prather, M., 1994: Lifetimes and eigenstates in atmospheric chemistry. *Geophys. Res. Lett.*, **21**, 801–804.

Prather, M., 2007: Lifetimes and time scales in atmospheric chemistry. *Philos. Trans. R. Soc. London A*, **365**, 1705–1726.

Prather, M. J., C. D. Holmes, and J. Hsu, 2012: Reactive greenhouse gas scenarios: Systematic exploration of uncertainties and the role of atmospheric chemistry. *Geophys. Res. Lett.*, **39**, L09803.

Reisinger, A., M. Meinshausen, and M. Manning, 2011: Future changes in global warming potentials under representative concentration pathways. *Environ. Res. Lett.*, **6**, 024020.

Rigby, M., et al., 2013: Re-evaluation of the lifetimes of the major CFCs and CH_3CCl_3 using atmospheric trends. *Atmos. Chem. Phys.*, **13**, 2691–2702.

Rothman, L., et al., 2009: The HITRAN 2008 molecular spectroscopic database. *J. Quant. Spectrosc. Radiat. Transfer*, **110**, 533–572.

Sato, M., J. E. Hansen, M. P. McCormick, and J. B. Pollack, 1993: Stratospheric aerosol optical depths, 1850–1990. *J. Geophys. Res. Atmos.*, **98**, 22987–22994.

Schmidt, G., et al., 2011: Climate forcing reconstructions for use in PMIP simulations of the last millennium (v1.0). *Geosci. Model Dev.*, **4**, 33–45.

Schmidt, G. A., et al., 2012: Climate forcing reconstructions for use in PMIP simulations of the Last Millennium (v1.1). *Geosci. Model Dev.*, **5**, 185–191.

Schrijver, C., W. Livingston, T. Woods, and R. Mewaldt, 2011: The minimal solar activity in 2008–2009 and its implications for long-term climate modeling. *Geophys. Res. Lett.*, **38**, L06701.

Sellevåg, S. R., C. J. Nielsen, O. A. Søvde, G. Myhre, J. K. Sundet, F. Stordal, and I. S. A. Isaksen, 2004: Atmospheric gas-phase degradation and global warming potentials of 2-fluoro ethanol, 2,2-difluoroethanol, and 2,2,2-trifluoroethanol. *Atmos. Environ.*, **38**, 6725–6735.

Shapiro, A., W. Schmutz, E. Rozanov, M. Schoell, M. Haberreiter, A. Shapiro, and S. Nyeki, 2011: A new approach to the long-term reconstruction of the solar irradiance leads to large historical solar forcing. *Astron. Astrophys.*, **529**, A67.

Shindell, D., and G. Faluvegi, 2010: The net climate impact of coal-fired power plant emissions. *Atmos. Chem. Phys.*, **10**, 3247–3260.

Shindell, D., G. Faluvegi, N. Bell, and G. Schmidt, 2005: An emissions-based view of climate forcing by methane and tropospheric ozone. *Geophys. Res. Lett.*, **32**, L04803.

Shindell, D., et al., 2008: Climate forcing and air quality change due to regional emissions reductions by economic sector. *Atmos. Chem. Phys.*, **8**, 7101–7113.

Shindell, D., et al., 2012: Simultaneously mitigating near-term climate change and improving human health and food security. *Science*, **335**, 183–189.

Shindell, D. T., G. Faluvegi, D. M. Koch, G. A. Schmidt, N. Unger, and S. E. Bauer, 2009: Improved attribution of climate forcing to emissions. *Science*, **326**, 716–718.

Shindell, D. T., et al., 2013: Radiative forcing in the ACCMIP historical and future climate simulations. *Atmos. Chem. Phys.*, **13**, 2939–2974.

Shine, K., J. Fuglestvedt, K. Hailemariam, and N. Stuber, 2005: Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases. *Clim. Change*, **68**, 281–302.

Sihra, K., M. Hurley, K. Shine, and T. Wallington, 2001: Updated radiative forcing estimates of 65 halocarbons and nonmethane hydrocarbons. *J. Geophys. Res. Atmos.*, **106**, 20493–20505.

Skeie, R., T. Berntsen, G. Myhre, K. Tanaka, M. Kvalevag, and C. Hoyle, 2011a: Anthropogenic radiative forcing time series from pre-industrial times until 2010. *Atmos. Chem. Phys.*, **11**, 11827–11857.

Skeie, R., T. Berntsen, G. Myhre, C. Pedersen, J. Strom, S. Gerland, and J. Ogren, 2011b: Black carbon in the atmosphere and snow, from pre-industrial times until present. *Atmos. Chem. Phys.*, **11**, 6809–6836.

Søvde, O. A., M. Gauss, S. P. Smyshlyaev, and I. S. A. Isaksen, 2008: Evaluation of the chemical transport model Oslo CTM2 with focus on arctic winter ozone depletion. *J. Geophys. Res. Atmos.*, **113**, D09304.

Steinhilber, F., J. Beer, and C. Frohlich, 2009: Total solar irradiance during the Holocene. *Geophys. Res. Lett.*, **36**, L19704.

Stevenson, D., R. Doherty, M. Sanderson, W. Collins, C. Johnson, and R. Derwent, 2004: Radiative forcing from aircraft NOx emissions: Mechanisms and seasonal dependence. *J. Geophys. Res. Atmos.*, **109**, D17307.

Stevenson, D. S., et al., 2013: Tropospheric ozone changes, radiative forcing and attribution to emissions in the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP). *Atmos. Chem. Phys.*, **13**, 3063–3085.

Svalgaard, L., and E. Cliver, 2010: Heliospheric magnetic field 1835–2009. *J. Geophys. Res. Space Phys.*, **115**, A09111.

Svalgaard, L., C. Mandrini, and D. Webb, 2012: How well do we know the sunspot number? *Comp. Magnet. Min. Character. Quiet Times Sun Stars*, **286**, 27–33.

Trenberth, K., and L. Smith, 2005: The mass of the atmosphere: A constraint on global analyses. *J. Clim.*, **18**, 864–875.

van Vuuren, D., J. Edmonds, M. Kainuma, K. Riahi, and J. Weyant, 2011: A special issue on the RCPs. *Clim. Change*, **109**, 1–4.

Wang, Y., J. Lean, and N. Sheeley, 2005: Modeling the sun's magnetic field and irradiance since 1713. *Astrophys. J.*, **625**, 522–538.

Wild, O., M. Prather, and H. Akimoto, 2001: Indirect long-term global radiative cooling from NOx emissions. *Geophys. Res. Lett.*, **28**, 1719–1722.

WMO, 1999: *Scientific Assessment of Ozone Depletion: 1998, Global Ozone Research and Monitoring Project*. World Meteorological Organisation, Report No. 44. World Meterological Organisation, Geneva, Switzerland.

WMO, 2011: *Scientific Assessment of Ozone Depletion: 2010*. Global Ozone Research and Monitoring Project Report. World Meteorological Organisation, Geneva, Switzerland, 516 pp.

Wright, J., 2004: Do we know of any Maunder minimum stars? *Astron. J.*, **128**, 1273–1278.