

Radiative forcing of carbon dioxide, methane and nitrous oxide: a significant revision of the methane radiative forcing

M. Etminan^a, G. Myhre^b, E.J.Highwood^a, K.P.Shine^a

^a Department of Meteorology, University of Reading, Reading RG6 6BB, UK

^b CICERO Center for International Climate and Environmental Research – Oslo, Norway

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Introduction

This Supporting Information includes 1 figure and 2 tables.

Figure S1 supports Figure 1 in the main text, which showed the change in net shortwave spectral irradiance at the tropopause for the specified changes in CO₂ and CH₄. Figure S1 shows the change in the upward and downward components of the irradiance that make up the net change. The figure emphasizes that the change in the downward irradiance always constitutes a negative radiative forcing, but the overall sign of the forcing depends on whether the change in upward irradiance is larger than this.

Table S1 which details the line-by-line calculations described in the main text, how the earlier MHSS98 simple expressions compare with these, and results using the new fits (Table 1 in the main text) based on fits to the new line-by-line calculations.

Table S2 shortwave forcing solar forcing for the line-by-line calculations comparing the all-sky CO₂ results, and the clear and all-sky results for CH₄, for the tropical and extratropical profiles used here. The purpose of this Table is to show the vital role of clouds (and the associated increase in reflected irradiance) in determining the sign of the CH₄ shortwave forcing.

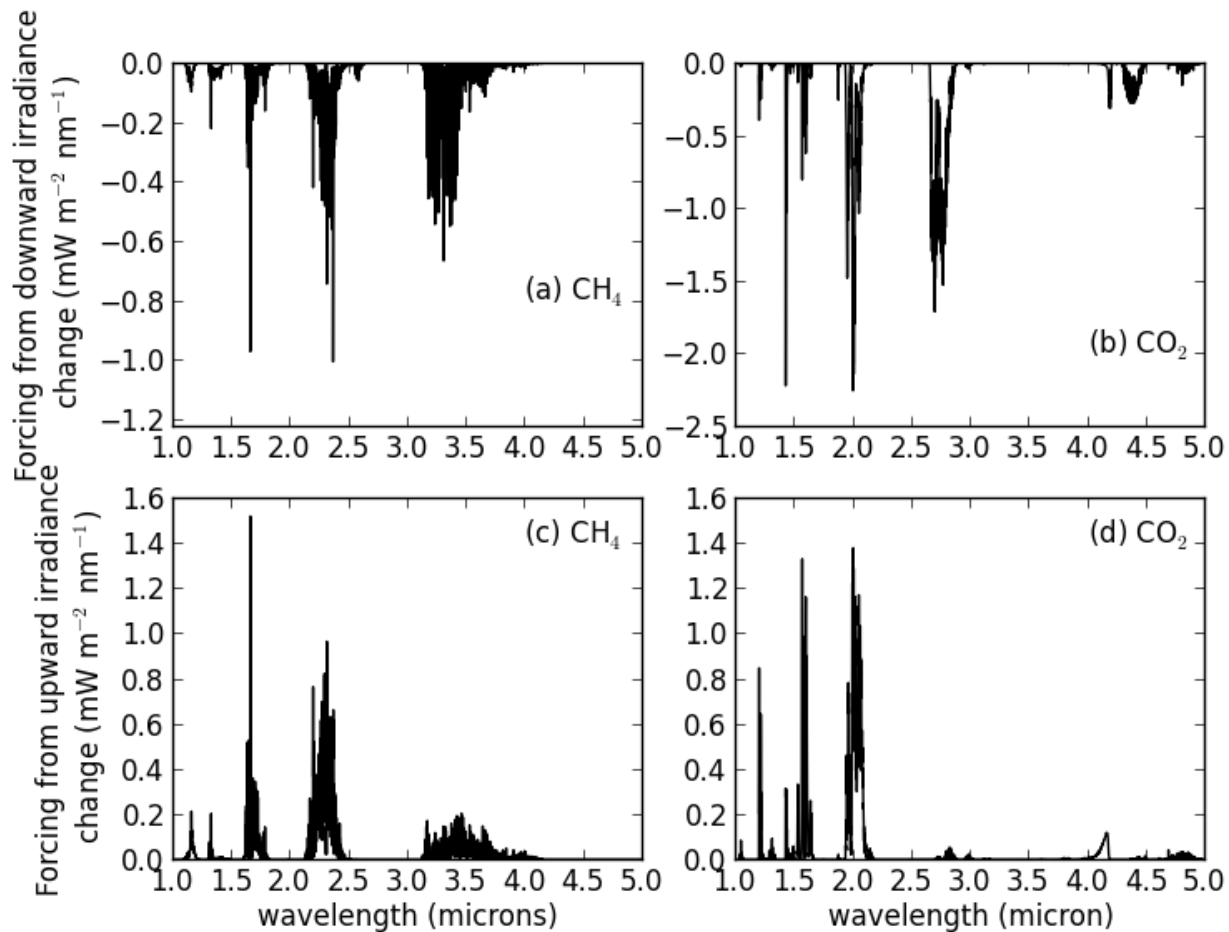


Figure S1. The spectral variation of the upwelling and downwelling components of the global-mean all-sky near-infrared radiative forcing (at the tropopause) shown in Figure 1 of the main text. (a) and (c) are the upwelling and downwelling forcing for CH₄ (750 to 1800 ppb) and (b) and (d) are the same for CO₂ (180 to 389 ppm).

Mixing Ratios				Radiative Forcing (W m^{-2})					Change	RF using new fits (W m^{-2})				
	CO ₂ (ppm)	CH ₄ (ppb)	N ₂ O (ppb)	SW	LW inst_cl	LW inst	LW adj	Net	relative to old fits (%)	CO ₂	N ₂ O	CH ₄	SUM	Error in new fits
1	389	1800	323	0	0	0	0	0		0.00	0.00	0.00	0.00	
2	389	1800	200	0.00	-0.50	-0.41	-0.41	-0.40	-2.4	0.00	-0.41	0.00	-0.41	0.5
3	389	1800	525	-0.01	0.67	0.55	0.54	0.53	-0.4	0.00	0.53	0.00	0.53	-0.6
4	389	750	323	-0.03	-0.64	-0.52	-0.55	-0.58	24.5	0.00	0.00	-0.58	-0.58	0.0
5	389	750	200	-0.03	-1.17	-0.95	-0.98	-1.01	14.4	0.00	-0.42	-0.59	-1.01	-0.3
6	389	750	525	-0.04	0.07	0.06	0.02	-0.02	-135.0	0.00	0.54	-0.57	-0.03	24.5
7	389	3500	323	0.03	0.65	0.53	0.57	0.60	17.1	0.00	0.00	0.62	0.62	2.7
8	389	3500	200	0.04	0.17	0.13	0.18	0.22	119.9	0.00	-0.39	0.63	0.24	8.1
9	389	3500	525	0.03	1.28	1.05	1.08	1.11	5.7	0.00	0.51	0.60	1.11	0.3
10	389	340	323	-0.05	-1.05	-0.85	-0.90	-0.95	26.6	0.00	0.00	-0.93	-0.93	-1.5
11	389	340	200	-0.05	-1.60	-1.30	-1.34	-1.39	19.6	0.00	-0.42	-0.95	-1.37	-1.8
12	389	340	525	-0.06	-0.32	-0.26	-0.31	-0.37	71.6	0.00	0.55	-0.91	-0.37	-0.4
13	180	1800	323	0.16	-5.28	-4.67	-4.20	-4.04	-2.0	-4.19	0.00	0.00	-4.19	3.6
14	180	1800	200	0.17	-5.80	-5.10	-4.63	-4.46	-1.7	-4.20	-0.41	0.00	-4.61	3.3
15	180	1800	525	0.16	-4.59	-4.10	-3.64	-3.49	-2.8	-4.17	0.53	0.00	-3.64	4.3
16	180	750	323	0.13	-5.91	-5.19	-4.75	-4.62	0.7	-4.19	0.00	-0.58	-4.77	3.2
17	180	750	200	0.13	-6.47	-5.64	-5.20	-5.06	1.2	-4.20	-0.42	-0.59	-5.21	2.8
18	180	750	525	0.12	-5.19	-4.59	-4.17	-4.04	-0.3	-4.17	0.54	-0.57	-4.19	3.8
19	180	3500	323	0.20	-4.63	-4.15	-3.64	-3.44	-4.7	-4.19	0.00	0.62	-3.57	3.7
20	180	3500	200	0.20	-5.13	-4.56	-4.04	-3.84	-4.6	-4.20	-0.39	0.63	-3.96	3.2
21	180	3500	525	0.19	-3.97	-3.60	-3.10	-2.91	-5.3	-4.17	0.51	0.60	-3.05	4.9
22	180	340	323	0.11	-6.32	-5.52	-5.10	-4.99	2.4	-4.19	0.00	-0.93	-5.12	2.7
23	180	340	200	0.11	-6.90	-5.99	-5.56	-5.45	3.0	-4.20	-0.42	-0.95	-5.57	2.2
24	180	340	525	0.10	-5.57	-4.91	-4.49	-4.39	1.2	-4.17	0.55	-0.91	-4.53	3.3
25	700	1800	323	-0.14	4.20	3.70	3.43	3.29	4.5	3.23	0.00	0.00	3.23	-1.8
26	700	1800	200	-0.14	3.71	3.30	3.03	2.90	6.1	3.23	-0.40	0.00	2.83	-2.2
27	700	1800	525	-0.15	4.84	4.23	3.94	3.80	3.3	3.21	0.52	0.00	3.74	-1.6
28	700	750	323	-0.17	3.56	3.18	2.88	2.70	1.1	3.23	0.00	-0.58	2.65	-2.2
29	700	750	200	-0.17	3.05	2.76	2.46	2.29	1.3	3.23	-0.41	-0.59	2.23	-2.5
30	700	750	525	-0.18	4.24	3.74	3.42	3.24	1.1	3.21	0.53	-0.57	3.18	-2.0
31	700	3500	323	-0.11	4.84	4.22	3.99	3.89	6.3	3.23	0.00	0.62	3.84	-1.1
32	700	3500	200	-0.10	4.38	3.85	3.62	3.52	8.5	3.23	-0.39	0.63	3.47	-1.2
33	700	3500	525	-0.11	5.45	4.73	4.49	4.37	4.4	3.21	0.50	0.60	4.32	-1.3
34	700	340	323	-0.19	3.15	2.85	2.53	2.34	-2.4	3.23	0.00	-0.93	2.29	-1.9
35	700	340	200	-0.19	2.62	2.42	2.10	1.91	-3.6	3.23	-0.42	-0.95	1.87	-1.9
36	700	340	525	-0.20	3.86	3.42	3.09	2.90	-1.1	3.21	0.54	-0.91	2.84	-2.0
37	2000	1800	323	-0.43	12.20	10.71	10.07	9.64	10.0	9.54	0.00	0.00	9.54	-1.0
38	2000	1800	200	-0.43	11.75	10.34	9.70	9.28	11.2	9.57	-0.38	0.00	9.18	-1.0

39	2000	1800	525	-0.44	12.80	11.20	10.55	10.11	8.8	9.51	0.50	0.00	10.01	-1.0
40	2000	750	323	-0.46	11.57	10.20	9.52	9.06	9.2	9.54	0.00	-0.58	8.96	-1.1
41	2000	750	200	-0.46	11.09	9.81	9.14	8.68	10.1	9.57	-0.39	-0.59	8.58	-1.0
42	2000	750	525	-0.47	12.20	10.71	10.03	9.56	8.3	9.51	0.51	-0.57	9.45	-1.2
43	2000	3500	323	-0.40	12.84	11.23	10.63	10.24	10.4	9.54	0.00	0.62	10.16	-0.7
44	2000	3500	200	-0.39	12.42	10.88	10.29	9.90	11.7	9.57	-0.37	0.63	9.83	-0.7
45	2000	3500	525	-0.41	13.41	11.69	11.09	10.69	9.0	9.51	0.48	0.60	10.59	-0.9
46	2000	340	323	-0.48	11.17	9.87	9.18	8.69	8.5	9.54	0.00	-0.93	8.61	-1.0
47	2000	340	200	-0.48	10.67	9.46	8.77	8.29	9.2	9.57	-0.40	-0.95	8.22	-0.9
48	2000	340	525	-0.49	11.82	10.40	9.70	9.21	7.8	9.51	0.51	-0.91	9.11	-1.1

Table S1. Global and Annual-mean radiative forcings (W m^{-2}) calculated using the Oslo Line-by-Line model, for gas concentration perturbations from the base case shown in the first row of the table, for CO_2 , CH_4 and N_2O concentrations shown in columns 2 to 4. The shortwave forcing is in Column 5, the instantaneous longwave clear-sky forcing is in Column 6, the instantaneous longwave all-sky forcing is in Column 7. Column 8 shows the longwave forcing after applying stratosphere temperature adjustment. Column 9 shows the net forcing (i.e. the sum of columns 4 and 7). Column 9 shows the change in these forcings, in percent, relative to that calculated using the MHSSg8 simple expressions. The next 4 columns show the forcings derived using the new expressions (Table 1 in the main text), for each gas separately, and for the sum; the final column gives the error in percent of these new expressions, relative to the line-by-line calculations.

Forcing (W m^{-2})	Tropics	Extratropics
CO_2	-0.18	-0.11
CH_4 clear	-0.04	-0.05
CH_4 all-sky	0.04	0.04

Table S2. Shortwave tropopause forcings (in W m^{-2}) for CO_2 increase from 180 to 389 ppm, and CH_4 from 750 to 1800 ppb separately for the tropics and extratropics profiles. The CH_4 forcings are shown for clear and all-skies.