Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6: Part I - Model Description and Calibration

- Supplementary Material-

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This supplementary material describes the input data series for emissions, radiative forcing, and optical thickness, which are used by MAGICC 6.0 as default for multi-forcing agent runs, if not otherwise stated. The individual radiative forcing series closely match the IPCC AR4 best forcing estimates in 2005 (see Table 1). A default set of complete radiative forcings is shown in Figure 1 for the SRES B1, A1B and A2 scenarios. Furthermore, the assumed default efficacies are listed in Table 2.

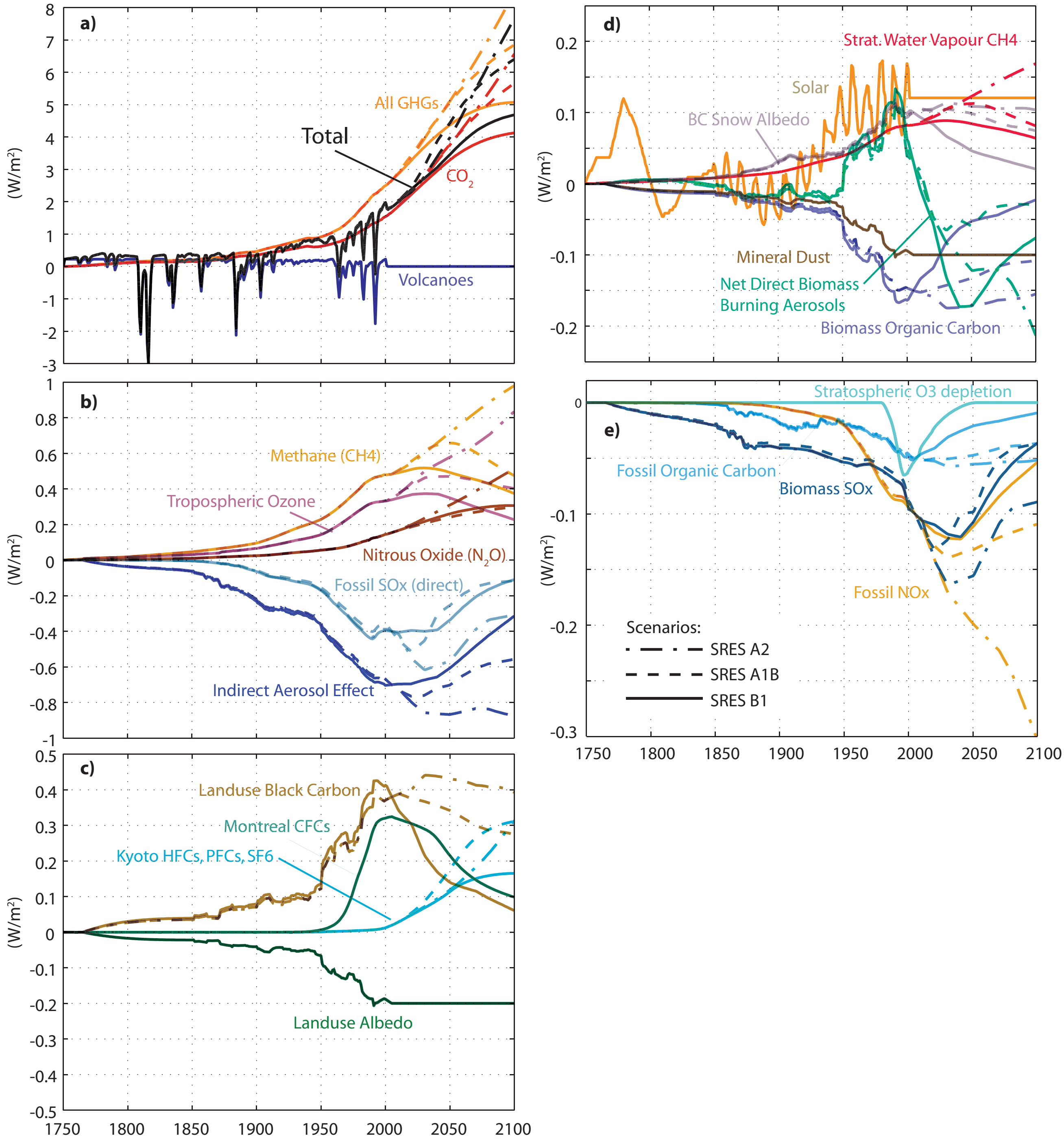

Figure 1 - Global mean radiative forcings within the 'full forcing' MAGICC6 emulations III shown for the three SRES scenarios A1B, A2, and B1. The regional forcings, i.e. for land and ocean on both hemispheres, differ substantially (not shown), especially for the aerosol species. As some forcings are temperature-dependent, the default CCSM3 emulation forcings are here used for illustration. The radiative forcings shown here are not modified by efficacies. Note that these default forcings used here differ from those used for producing GHG concentrations of the RCP pathways (Meinshausen et al. submitted), as documented on http://www.pik-potsdam.de/~mmalte/rcps/.

Table 1 - Overview of default MAGICC input dataseries for emissions, abundances, optical thickness and forcings, the default 2005 forcing in comparison with the IPCC AR4 best-estimate and the derivation of future forcings.

Forcing Agent / Emissions	Historical Emissions / Abundances / Forcing	Present 2005 forcing (MAGICC / IPCC AR4 best-estimate; W/m^2)	Future Forcing
	Long-Lived GHGs		
Carbon Dioxide (CO_2)	Prescribed concentrations up to 2000. Up to 1850: Law Dome Ice Core data (Etheridge et al. 1996)[b], 75yr smoothed; until 2000: as in NASA GISS 2002 GCM simulations[a] building on 1850-1953: Etheridge et al. (1996); 1958-1974: SIO Sampling Nethwork (Keeling and Whorf 2004); 1975-1982: NOAA CMDL In-Situ (Tans and Thoning 2005); 1983-2000: NOAA CMDL (Tans and Conway 2006). Constant Radiative Forcing Pattern as presented by Hansen et al. (2005).	*+1.69 / +1.66*	Using scenario total CO_2 emissions and MAGICC carbon cycle - see Appendix A.
Methane (CH_4)	Prescribed concentrations up to 2000. Up to 1850: Law Dome Ice Core data (Etheridge et al. 1998)[c], 75yr smoothed ; until 2000: as in NASA GISS 2002 GCM simulations[a] 1850-1980: Etheridge et al. (1998); 1984-2003: E. Dlugokencky (NOAA CMDL[a]). Constant Radiative Forcing Pattern as presented by Hansen et al. (2005).	*+0.48/+0.48*	Using scenario total CH_4 emissions and MAGICC routines - see Appendix A.
Nitrous Oxide (N_2O)	Prescribed concentrations up to 2004. Up to 1850: Flückiger et al. (2002) - 300yr cutoff spline; until 2004: as in NASA GISS 2002 GCM simulations: 1850-1977: Machida et al. (1995) ; 1978-1999: NOAA CMDL Flask Datad; 2000-2004: G.S. Dutton, T.M. Thompson, J.W. Elkins & B.D. Hall (NOAA CMDL In-Situ Data)[e]. Constant Radiative Forcing Pattern as presented by Hansen et al. (2005).	*+0.16/+0.16*	Using scenario total N_2O emissions and MAGICC routines - see Appendix A.
Ozone Depleting Substances (ODS)	Prescribed concentrations up to 2000 for 16 halogenated gases controlled under the Montreal protocol (CFC11, CFC12, CFC113, CFC114, CFC115, CARB_TET, MCF, HCFC22, HCFC141B, HCFC142B, HALON1211, HALON1202, HALON1301, HALON2402, CH_3BR, CH_3CL) as in Scenario A1 presented in WMO 2002 Ozone Assessment (UNEP/WMO 2002), kindly provided by John Daniel (NOAA) and Guus Velders (MNP, Netherlands). Constant Radiative Forcing Pattern as presented by Hansen et al. (2005) for CFC-11 for the long-lived gases and scaled patterns for shorter lived gases (see text).	*+0.33/+0.35(incl. FGAS)*	Using scenario A1baseline (Beijing Amendment) emissions of WMO 2006 Ozone Assessment and MAGICC as described in Appendix A.
Halocarbons controlled under the Kyoto Protocol (FGAS)	Prescribed concentrations up to 2000 for 12 halogenated gases (CF4,C2F6, C4F10, HFC23, HFC32, HFC43_10, HFC125, HFC134a, HFC143a, HFC227ea, HFC245ca, SF6) controlled under the Kyoto protocol as used in NASA GISS 2002 simulations[f]: 1850-1977/2004: IPCC (2001), 1978-1991: NOAA Flask & In-Situ; 1992-2000: Update from Montzka et al. (1999). Radiative Forcing Pattern as presented by Hansen et al. (2005) for CFC-11 (gases with lifetime >8yrs) , see text for short lived gases' forcing patterns.	*+0.02/+0.35 (incl. ODS)*	Using scenario emissions for 12 individual halogenated Kyoto gases and MAGICC algorithms - see Appendix A.

Table 1 (continued).

Forcing Agent / Emissions	Historical Emissions / Abundances / Forcing	Present 2005 forcing (MAGICC / IPCC AR4 best-estimate; W/m^2)	Future Forcing
	Direct forcing by Fossil related aerosols		
Industrial Black Carbon (BCI)	Radiative Forcing pattern of year 2000 by Hansen et al. (2005) (Runs E2BCIx2a-E2AarM20A)[h]; scaled back in time by column optical thickness pattern as estimated by the GISS (Hansen et al. 2005)[g], where column optical thickness is interpolated to annual values using fossil black carbon emissions provided by Novakov et al. (2003).	+0.20/+0.20	Scaled with fossil black carbon emissions that are estimated from the fossil CO emissions using a relative ratio factor from 1 in 2004 to 0.4 in 2100[l]. Often, emission scenarios, like SRES, only provide total CO emissions though. The fossil CO emissions are hence estimated from the emission scenarios' total CO emissions using a ratio between fossil and biomass emissions as in year 2000 of the EDGAR 3.2 database (Olivier and Berdowski 2001).
Industrial Nitrate Aerosols (NOXI)	Radiative Forcing pattern of year 2000 by Hansen et al. (2005) for total NOx (Runs E2NO3x5a-E2AarM20A)[h] scaled back in time by joint fossil, industrial and biomass related column optical thickness patterns as estimated by the GISS model (Hansen et al. 2005)[g]; where column optical thickness is interpolated to annual values using hemispheric NO_X emissions according to gridded datasets EDGAR3.2 (1990-2000 and EDGAR-HYDE 1.3 (1890-1990) (Van Aardenne et al. 2001), the latter being scaled to match EDGAR3.2 1990 hemispheric emissions. The time-variable total NOx radiative forcing is split to fossil and biomass related forcing using the respective emissions ratios in each hemisphere.	-0.10/-0.10	Scaled using fossil NOx emissions. The fossil NOx emissions are estimated from the emission scenarios' total NOx emissions using a ratio between fossil and biomass emissions as in year 2000 of the EDGAR 3.2 database (Olivier and Berdowski 2001).
Industrial Organic Carbon (OCI)	Radiative Forcing pattern of year 2000 by Hansen et al. (2005) (Runs E2OCIx6a-E2AarM20A)[h] scaled back in time by column optical thickness pattern as estimated by the GISS model (Hansen et al. 2005)[g]; where column optical thickness patterns are extra- and interpolated to annual values using hemispheric carbon dioxide emissions provided by Marland et al. (2006).	-0.05 / -0.05	As fossil black carbon emissions (see above) using the same ratio factor to estimate future organic carbon emissions from carbon monoxide (CO) emissions.
Industrial Sulphate Aerosols (SOXI)	Radiative Forcing pattern of year 2000 by Hansen et al. (2005) (Runs E2**SUIx**2a-E2AarM20A)[i,h]; scaled back in time by column optical thickness pattern as estimated by the GISS model (Hansen et al. 2005)[g]; where column optical thickness patterns are extra- and interpolated to annual values using hemispheric fossil SOx emissions according to, the latter being scaled to match EDGAR32 1990 hemispheric emissions.	-0.40 / -0.40	Scaled using fossil SOx emissions. The fossil SOx emissions are estimated from the emission scenarios' total SOx emissions using a ratio between fossil and biomass emissions as in year 2000 of the EDGAR 3.2 database (Olivier and Berdowski 2001).

Table 1 (continued).

Forcing Agent / Emissions	Historical Emissions / Abundances / Forcing	Present 2005 forcing (MAGICC / IPCC AR4 best-estimate; W/m^2)	Future Forcing
	Direct forcing by Biomass burning related aerosols		
Biomass Burning Black Carbon (BCB)	Radiative Forcing pattern of year 2000 by Hansen et al. (2005) (Runs E2BCBx6a-E2AarM20A)[h]; scaled back in time by column optical thickness pattern as estimated by the GISS model (Hansen et al. 2005)[g]; where column optical thickness patterns are extra- and interpolated to annual values using landuse carbon dioxide emissions provided by Houghton and Hackler (2002).	+0.38 / - (see sum)	Scaled with biomass burning black carbon emissions that are estimated from the biomass burning CO emissions using a relative ratio factor from 1 in 2004 to 0.4 in 2100[l]. The biomass burning CO emissions are estimated from the emission scenarios' total CO emissions using a ratio between fossil and biomass burning emissions as in year 2000 of the EDGAR 3.2 database (Olivier and Berdowski 2001). Note that the absolute magnitude of the positive forcing has been scaled by a factor of two above the 1850-2000 estimate (+0.19 W/m2) by Hansen et al. (2005)[g] in order to match the overall best estimate by IPCC AR-4 of +0.03 for all biomass burning related aerosols.
Biomass Burning Nitrous Oxide (NOXB)	Radiative Forcing pattern of year 2000 by Hansen et al. (2005) for total NOx (Runs E2NO3x5a-E2AarM20A)[h] scaled back in time by joint fossil, industrial and biomass related column optical thickness patterns as estimated by the GISS model (Hansen et al. 2005)[g]; where column optical thickness is interpolated to annual values using hemispheric NO_X emissions according to gridded datasets EDGAR3.2 (1990-2000) (Olivier and Berdowski 2001) and EDGAR-HYDE 1.3 (1890-1990) (Van Aardenne et al. 2001), the latter being scaled to match EDGAR32 1990 hemispheric emissions. The time-variable total NO_X radiative forcing is split to fossil and biomass related forcing using the respective emissions ratios in each hemisphere.	-0.10 / - (see sum)	Scaled using biomass burning NOx emissions. The biomass burning NOx emissions are estimated from the emission scenarios' total NOx emissions using a ratio between fossil and biomass emissions as in year 2000 of the EDGAR 3.2 database (Olivier and Berdowski 2001).
Biomass Burning Organic Carbon (OCB)	Radiative Forcing pattern of year by Hansen et al. (2005) (Runs E2OCBx6a-E2AarM20A)[h]; scaled back in time by column optical thickness pattern as estimated by the GISS model (Hansen et al. 2005)[g]; where column optical thickness patterns are extra- and interpolated to annual values using landuse carbon dioxide emissions provided by Houghton and Hackler (2002).	-0.15/ - (see sum)	Scaled with biomass burning organic carbon emissions that are estimated from the biomass burning CO emissions using a relative ratio factor from 1 in 2004 to 0.4 in 2100[l]. See biomass burning related black carbon emissions above.

Table 1 (continued).

Forcing Agent / Emissions	Historical Emissions / Abundances / Forcing	Present 2005 forcing (MAGICC / IPCC AR4 best-estimate; W/m^2)	Future Forcing
Biomass Burning Sulphate Aerosols (SOXB)	Radiative Forcing pattern of year 2000 by Hansen et al. (2005) (Runs E2**SUIx**2a-E2AarM20A)[i,h]; scaled back in time by column optical thickness pattern as estimated by the GISS model (Hansen et al. 2005)[g]; where column optical thickness patterns are extra- and interpolated to annual values using hemispheric landuse SO_X emissions according to gridded datasets EDGAR3.2 (1990-2000) (Olivier and Berdowski 2001) and EDGAR-HYDE 1.3 (1890-1990) (Van Aardenne et al. 2001), the latter being scaled to match EDGAR32 1990 hemispheric emissions.	-0.10 / - (see sum)	Scaled using SOx emissions. The biomass burning SOx emissions are estimated from the emission scenarios' total SOx emissions using a ratio between fossil and biomass emissions as in year 2000 of the EDGAR 3.2 database (Olivier and Berdowski 2001).
Direct Biomass Burning Aerosols (BIOMASS-AER)	The biomass related aerosol emissions are the sum of the above biomass-related black carbon, organic carbon, nitrate and sulphate oxide aerosols.	+0.03 / +0.03	Sum of the biomass burning related aerosol emissions.
	Indirect forcing by aerosols		
Cloud Albedo Effect (CLOUD_ALBEDO)	Since no adjusted radiative forcing pattern was available, the fixed SST pattern provided by Hansen et al. is used (ANN 1961-2050 E3IE1M20A). Scaling over time with optical thickness patterns for sulphate dioxide, black carbon, organic carbon, and nitrates provided by (Hansen et al. 2005)[g], which are extra- and interpolated to annual values by the respective emissions, as described above for the forcing of industrial/fossil and biomass burning related aerosol direct effects. For the calculation of the indirect aerosol effect, see Appendix A for further details.	-0.70 / -0.70	Individual optical thickness pattern are scaled by the respective emissions, as described for the direct forcing.
Cloud Lifetime Effect (CLOUD_COVER)	Since no adjusted radiative forcing pattern was available, the fixed SST pattern provided by Hansen et al. is used (Run ANN 1961-2050 E3IE2M20A). Scaling over time with optical thickness patterns for sulphate dioxide, black carbon, organic carbon, and nitrates provided by (Hansen et al. 2005)[g], which are extra- and interpolated to annual values by the respective emissions, as described above for the forcing of industrial/fossil and biomass burning related aerosol direct effects. For the calculation of the indirect aerosol effect, see Appendix A for further details.	- (-0.70) / -	IPCC AR-4 considers the cloud lifetime effect as efficacy term for Cloud Albedo radiative forcing. Thus, not included in future MAGICC projection by default. Exception (brackets): tuning of GISS-EH and GISS-ER models, which include only the cloud lifetime, but not the cloud cover effects according to table 10.2 in Meehl et al. (2007).

Table 1 (continued).

Forcing Agent / Emissions	**Historical Emissions / Abundances / Forcing**	**Present 2005 forcing (MAGICC / IPCC AR4 best-estimate; W/m^2)**	**Future Forcing**
	Other Forcings		
Surface albedo – black carbon aerosol on snow (BCSNOW)	Radiative Forcing pattern of year 2000 by Hansen et al. (2005) (Runs E2SNAa-E2arM20A)[h] ; scaled back in time by combined column optical thickness patterns of fossil and landuse black carbon as estimated by the GISS model (Hansen et al. 2005)[g]; See black carbon direct forcing BCI and BCB above.	+0.10 / +0.10	Forcing scaled with future fossil and biomass burning black carbon emissions. See black carbon direct forcing.
Direct Mineral Dust Aerosol. (MINERALDUST)	Radiative Forcing pattern is assumed proportional to the time-independent one provided for soil dust (Runs E2a-E2noDSTarM20A); scaled back in time by cumulative global landuse CO_2 emissions (Houghton 1999; Houghton and Hackler 2002) as proxy.	-0.10 / -0.10	Assumed constant after year 2000.
Surface Albedo – landuse (LANDUSE)	The radiative forcing pattern for the change between 1911-2000 by Hansen et al. (2005) (Run E2CRPM20A)[h] is scaled back in time using hemispheric landuse CO_2 emissions (Houghton 1999; Houghton and Hackler 2002) as proxy.	-0.20 / -0.20	Assumed constant after year 2000.
Stratospheric Ozone (STRATOZ)	Radiative forcing modelled by MAGICC using prescribed concentrations. Historical prescribed concentrations are taken from the WMO 2002 Ozone Assessment (UNEP/WMO 2002), kindly provided by John Daniel (NOAA) and Guus Velders (MNP, Netherlands).	-0.05 / -0.05	Radiative forcing modelled by MAGICC using calculated concentrations. Future concentrations are calculated based on scenario A1 emissions presented in WMO 2006 Ozone Assessment (UNEP/WMO 2002; WMO 2006), kindly provided by John Daniel (NOAA) and Guus Velders (MNP, Netherlands).
Tropospheric Ozone (TROPOZ)	Radiative forcing modelled by MAGICC using historical hemispheric emissions of nitrous oxide (NO_X), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC) – see Appendix A. Historical hemispheric industrial/fossil and landuse NO_X, CO and NMVOC emissions were derived from the gridded datasets EDGAR3.2 (1990-2000) (Olivier and Berdowski 2001) and EDGAR-HYDE 1.3 (1890-1990) (Van Aardenne et al. 2001), the latter being scaled to match EDGAR3.2 1990 hemispheric emissions.	+ 0.35 / +0.35	Radiative forcing modelled by MAGICC using future scenario emissions for NOx, CO, NMVOC – see Appendix A.
Stratospheric Water Vapour from CH_4 (CH4OXSTRATH2O)	Modelled by MAGICC based on prescribed CH_4 concentrations. See Appendix A.	+0.07 / +0.07	Modelled by MAGICC based on calculated CH_4 concentrations. See Appendix A.

Table 1 (continued).

Forcing Agent / Emissions	Historical Emissions / Abundances / Forcing	Present 2005 forcing (MAGICC / IPCC AR4 best-estimate; W/m^2)	Future Forcing
	Natural forcing		
Solar Forcing (SOLAR)	Radiative forcing 1850-2000 assumed proportional to the instantaneous forcing as computed in the NASA GISS Model E (Judith Lean)[j] – scaled to match user-defined 2004 forcing level. Pre-1850: Solar forcing as provided by Hegerl et al. (2006) but shifted and scaled in amplitude to match the difference in the 1850-1860 to 1990-2000 means of the GISS Model E forcing series.	+0.12 / +0.12	Assumed as the mean over the last 11year cycle 1994-2004.
Volcanic forcing / Stratospheric Aerosols (VOLCANIC)	Using hemispheric monthly-mean optical thickness 1850-2000 at 550nm as used in the NASA GISS E model (Sato et al. 1993; Hansen et al. 2005)[k] and transformed into adjusted forcing using a conversion factor of -25 W/m^2. Pre-1850: Using global reconstruction of volcanic forcing by ice core data from Greenland and Antarctica by Crowley et al. (2003) as in Hegerl et al. (2006), linearly interpolated to monthly values. In contrast to all other annual-mean forcings, MAGICC 5.0 uses monthly mean volcanic values – due to the high time-variability of volcanic forcing at times of eruptions. By default, historical volcanic forcing is adjusted to a mean zero. Furthermore, a scaling factor of 0.7 is applied as default to approximately match the net volcanic forcing magnitude applied in the majority of the CMIP3 AOGCMs, which included volcanic forcings.	0.0 / -	Assumed as the mean over the historical period, which has been adjusted to zero by default.

Notes	
a	See http://data.giss.nasa.gov/modelforce/ghgases/, accessed May 2007
b	See ftp://ftp.ncdc.noaa.gov/pub/ data/paleo/icecore/antarctica/ law/law_co2.txt, accessed May 2007
c	See ftp://ftp.ncdc.noaa.gov/pub/data/ paleo/icecore/antarctica/law/law_ch4.txt, accessed May 2007
d	See ftp://ftp.cmdl.noaa.gov/hats/n2o/flasks, accessed May 2007
e	See ftp://ftp.cmdl.noaa.gov/hats/n2o/insituGCs/CATS/global/insitu_global_N2O, accessed May 2007
f	See http://data.giss.nasa.gov/modelforce/ghgases/TG_A.1930-1990.txt and http://data.giss.nasa.gov/modelforce/ghgases/TG_A.1992-2005.txt, accessed May 2007
g	See data available at http://data.giss.nasa.gov/modelforce/trop.aer/AOT.dat
h	See http://data.giss.nasa.gov/efficacy/
i	Note that the run name E2SUIx2a is here taken from the file provided on http://data.giss.nasa.gov/efficacy/ although Table 2 in Hansen et al. (2005) suggest the runname being E2SUx2a, considering total Sox aerosol direct effects.
j	See http://data.giss.nasa.gov/modelforce/solar.irradiance/forcing.data.txt
k	See http://data.giss.nasa.gov/modelforce/strataer/
l	As many emission scenarios do not provide black carbon emissions, including the SRES scenarios, MESSAGE mitigation scenarios (Rao et al. 2005; Rao and Riahi 2006) were chosen for estimating the gas whose emissions seem to be correlating best with black and organic carbon allowing for a time-variable, but linear, emission ratio factor. The black carbon and carbon monoxide emissions seem to have correlated best with CO, with the relative emission ratio decreasing from 1 in 2004 to 0.4 in 2100.

Table 2 – Default efficacies used in this study and comparison with values cited in IPCC AR4.

Forcing agent	Default in this study	IPCC AR4	Comment[a]
Carbon Dioxide (CO_2)	1.0	1.0	By definition
Methan (CH_4)	1.0	1.0 – 1.2 / "close to 1"	Mean of IPCC AR4 range chosen. Figure 2.20 in Forster et al. (2007) denotes 1.0-1.2 for Long-Lived Greenhouse Gases. Section 2.8.5.2 specifies "slightly higher than 1" and "close to 1 (within 10%)".
Stratospheric Water Vapour from CH_4 (CH4OXSTRATH2O)	1.0	"roughly 1"	IPCC AR-4 only mentions that results from Hansen et al. (2005) and Forster & Shine et al. (1999) are "roughly one" (section 2.8.5.7).
Nitrous Oxide (N_2O)	1.0	1.0 to 1.2 / "close to 1"	See CH_4 above.
Stratospheric Ozone (STRATOZ)	1.25	0.5 to 2.0	See section 2.8.5.4 and Figure 2.20.
Tropospheric Ozone (TROPOZ)	0.85	0.6 to 1.1	Mean of IPCC AR-4 range chosen. See section 2.8.5.4.
Direct Aerosol effects	0.9	0.7 to 1.1	Mean of IPCC AR-4 estimate chosen. IPCC AR-4 suggest for scattering aerosol effects that efficacies are in the range 0.7 to 1.1. Note that IPCC AR-4 does not give consensus estimates of efficacies for absorbing black carbon, for which the concept of a linear response could "break down" and efficacies could be negative.
First indirect, cloud albedo effect (incl. / excl. cloud lifetime effect.)	0.9 / 1.5	0.7 to 1.1 / 1.0 to 2.0	Efficacy estimates distinguish between the case, where the cloud albedo efficacy accounts for the effective radiative forcing exerted by the cloud lifetime effect, or not. IPCC AR-4 states that "if cloud lifetime effects were excluded from the efficacy term, the cloud albedo efficacy would very likely be similar to that of the direct effect. Thus, the mean of 0.7 to 1.1, i.e. 0.9 is chosen here as default for the cloud albedo efficacy. However, the very uncertain efficacy when cloud lifetime effects are includes are very uncertain, given in figure 2.20 as 1.0 to 2.0. The respective mean is here chosen as default, if cloud efficacies are included (e.g. when tuning MIROC 3.2 models).
Solar Forcing (SOLAR)	0.085	0.7 to 1.0	See figure 2.20.
Volcanic Forcing (VOLC)	0.95	0.7 to 1.1	IPCC AR-4 notes that "efficacies are likely to be similar for scattering aerosols in the troposphere and the stratosphere". The mean of the given 0.7 to 1.1 range is chosen as default.
Surface Albedo – landuse (LANDUSE)	1.0	-	
Surface albedo – black carbon aerosol on snow (BCSNOW)	1.7	1.7	IPCC AR-4 only cites the study by Hansen et al. (2005).
Ozone Depleting Substances (ODS)	1.0	1.0 – 1.2 / "close to 1"	The efficacy here assumed 1.0 given the large range of gases in this group and the associated uncertainty, although efficacies could be slightly higher than 1. See Methane above.
Halocarbons controlled under the Kyoto Protocol (FGAS)	1.0	1.0 – 1.2 / "close to 1"	The efficacy here assumed 1.0 given the large range of gases in this group and the associated uncertainty, although efficacies could be slightly higher than 1. See Methane above.

Notes	
a	If not otherwise stated, figure and section numbers refer to IPCC AR4: Forster et al. (2007)

References Supplementary Material

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