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Abstract

The preliminary emission scenarios in the Special Report on Emission Scenario (SRES) developed by the Intergovernmental Panel on Climate Change (IPCC), will eventually replace the old IS92 scenarios. By running these scenarios in a simple climate model (SCM) we estimate future temperature increase between 1.7°C and 2.8°C from 1990 to 2100. The global sea level rise over the same period is between 0.33 m and 0.45 m.

Compared to the previous IPCC scenarios (IS92) the SRES scenarios generally results in changes in both development over time and level of emissions, concentrations, radiative forcing, and finally temperature change and sea level rise. The most striking difference between the IS92 scenarios and the SRES scenarios is the lower level of SO_2 emissions. The range in CO_2 emissions is also expected to be narrower in the new scenarios. The SRES scenarios results in a narrower range both for temperature change and sea level rise from 1990 to 2100 compared to the range estimated for the IS92 scenarios.

Contents

1 Introduction

In this paper we use a simple climate model (SCM) to examine the effects of future climate gas emissions on global mean temperature and sea level. The new set of preliminary emission scenarios from the Intergovernmental Panel of Climate Change (IPCC) presented in the Special Report on Emissions Scenarios (SRES) (IPCC, 1999) provides the future emission profiles in these model calculations.

The emission profiles in the new scenarios have quite different levels and range compared to the previous set of scenarios from IPCC (IS92). The main difference between the old (IS92) and new emission scenarios (SRES) is that the latter have lower emissions of sulfur dioxide (SO_2). In addition to the new emission profiles, updated model parameters are applied in this scenario study.

Due to large differences between the new and old scenarios, we have included a comparison to point out what implications such differences may have on the modelled radiative forcing, temperature change and sea level rise.

2 The model

Figure 1 shows the overall structure of the simple climate model (SCM) applied in this scenario study.

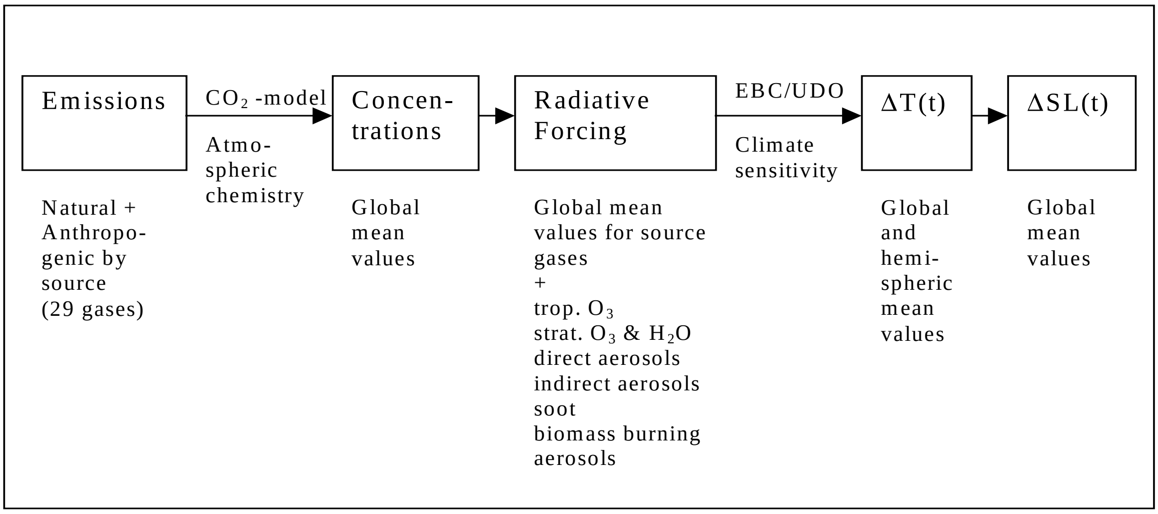

Figure 1. The structure of the simple climate model (SCM).

The climate gases included in the model constitute 29 source gases (see Appendix). The atmospheric concentrations are calculated for all these gases except SO_2. Radiative forcing is calculated for these gases and for tropospheric and stratospheric ozone (O_3), stratospheric water vapour (H_2O), sulphate and soot aerosols, aerosols from biomass burning. Indirect forcing from aerosols through effects on clouds is also taken into account in a simplified manner.

For the period 1750 to 1990 historical concentrations for all gases, except carbon dioxide (CO_2) and SO_2, are applied based on various sources. For CO_2 the concentrations are calculated from 1750 up to the present and then further into the future (see Joos et al., 1996; Alfsen and Berntsen, 1999). For the period beyond 1990 various scenarios are applied.

The calculated forcing from 35 atmospheric components based on emission scenarios, form input to the energy-balance-climate/upwelling-diffusion-ocean (EBC/UDO) model developed by Schlesinger (see Appendix). With prescribed values for climate sensitivity[1], the model calculates changes in global and hemispheric mean temperatures as well as sea level rise due to thermal expansion of the ocean and melting of glaciers. The calculations are based on formulations for the exchange of energy between the atmosphere and the water surface and further down to the deep layers.

The surface layer of the ocean is set to a thickness of 75 meters, whereas the underlying part is split into 40 layers, each of thickness 100 meters. The transportation of cold water directly to the deep oceans in the polar regions is accounted for. For further details of this model, see Schlesinger et al. (1992). The EBC/UDO model has a similar structure as the model used by IPCC in the Second Assessment Report (SAR) (IPCC, 1996) as described in IPCC (1997).

3 Emission scenarios

The climate simulations presented in this paper are based on preliminary emission figures now available in IPCCs Special Report on Emission Scenarios (http://sres.ciesin.org/). The review of the scenarios has not yet been completed and changes may occur in the final preparation. Compared to the previous IS92 scenarios (IPCC, 1992) the new set of scenarios represents a different methodological approach. The Special Report show 40 new scenarios constructed around four equally realistic futures, based on distinctly different assumptions about world population, economic development and technological progress. The model run that best represents each story line is designated as a "marker scenario". An overview of the underlying assumptions of the new IPCC marker scenarios follows.

Scenario A1, *the rich world*, is characterised by very rapid economic growth (3% per year) low population growth (0.27 % per year) and rapid introduction of new and more efficient technology. Globally there is economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income.

In Scenario A2, *the separated world*, cultural identities are separating the different regions making the world more heterogeneous and international co-operation less likely. “Family values” and local traditions, high population growth (0.83 % per year) is emphasised. And less focus on economic development (1.65% per year) and material wealth. Other regions define the generation of knowledge and economic growth as the overall aim.

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[1] Climate sensitivity usually refers to the long-term (equilibrium) change in global mean surface temperature following a doubling of atmospheric CO_2 (or equivalent CO_2). Due to large uncertainties IPCC gives an interval of 1.5°C to 4.5°C for this sensitivity (IPCC, 1996). More generally, it refers to the equilibrium change in surface air temperature following a unit change in radiative forcing (°C/Wm^{-2}).

Scenario B1, *the sustainable world*, describes rapid change in economic structures, "dematerialization" including improved equity, and environmental concern. There is a global concern regarding environmental and social sustainability and more effort in introducing clean technologies. The global population reaches seven billion by 2100.

Scenario B2, *the world of technological inequalities*, shows a heterogeneous society emphasising local solutions to economic, social, and environmental sustainability rather than global solutions. Human welfare, equality and environmental protection all have high priority.

Compared to the IS92 scenarios the SRES emission trajectories do not show a similar "fanlike" pattern. The new scenarios do not typically show smooth and increasing trajectories with gradual and systematic variations from low emission to high emission, but rather show individual trajectories manifesting the very different underlying assumptions about future development in key factors.

The emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur dioxide (SO_2), are presented in the following graphs.

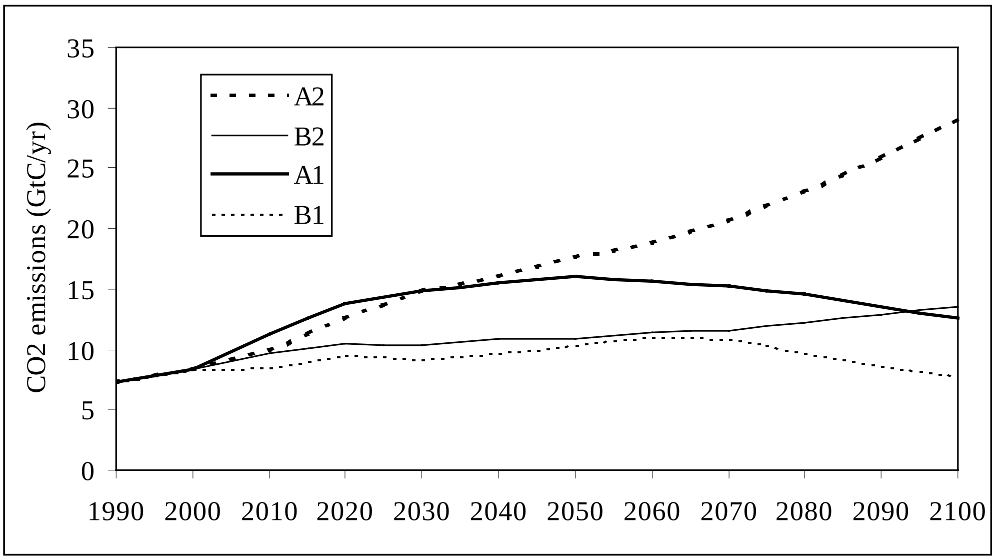

Figure 2. Global anthropogenic CO_2 emissions, GtC per year.

The anthropogenic carbon emission figures include both emissions from the combustion of fossil fuels, industrial processes and from deforestation. According to Figure 2 the A2 scenario has the highest emissions of CO_2 in 2100, reaching a level of 29 GtC/yr. The B1 scenario has the lowest emission levels at the end of the century, reaching 8 GtC/yr. The large range between the A2 and B1 scenario may be explained from the assumption of the A2 world with high population, high energy and carbon intensity, and correspondingly high CO_2 emissions. The A2 scenario shows similar emission trends for other greenhouse gases, with the exception of SO_2 emissions.

The range between the high and low CO_2 emission scenarios is not as large as in the IS92 scenarios. The range between the minimum and maximum emission levels in the IS92 scenarios is from 4.6 to 35.8 GtC/yr in 2100. The new range in the SRES scenarios is from almost 8 to 29 GtC/yr.

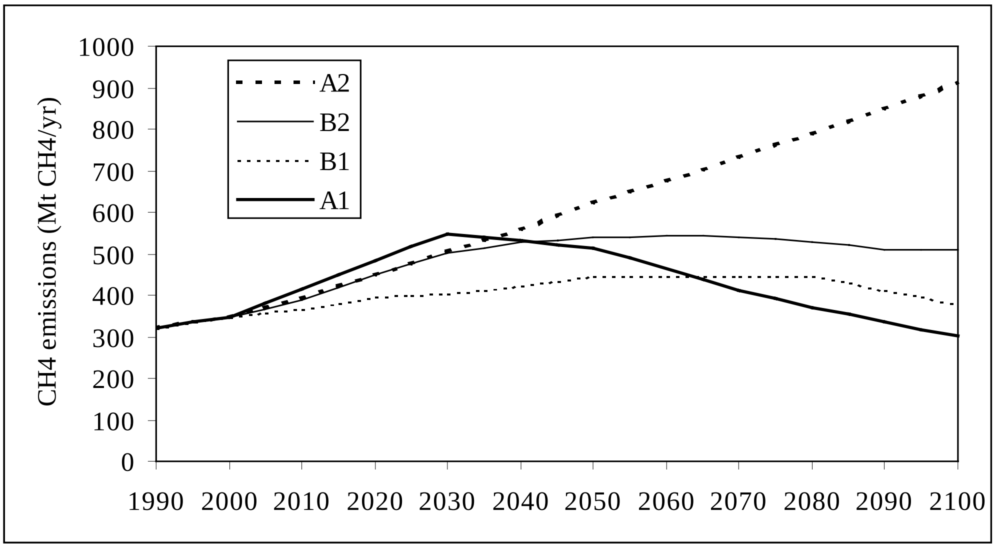

Figure 3. Global anthropogenic CH_4 emissions, $MtCH_4$ per year.

According to the A2 scenario the anthropogenic emissions of CH_4 will reach a level of 900 $MtCH_4$/yr within the end of the century. The natural emissions of CH_4 are 160 $MtCH_4$/yr (IPCC, 1999). The other scenarios show more modest emission forecasts ranging from 300 to 500 $MtCH_4$/yr. Having the highest emission in 2030 the A1 scenario show a decreasing emission trend levelling off below current annual emission levels.

Similar to the CO_2 emission trajectory the emissions of CH_4 also narrow down the differences between minimum and maximum emission levels compared to the IS92 scenarios. The old scenario (IS92) range is from 546 to 1168 $MtCH_4$/yr. The new scenarios (SRES) vary from a low of approximately 300 $MtCH_4$/yr to a high of almost 913 $MtCH_4$/yr.

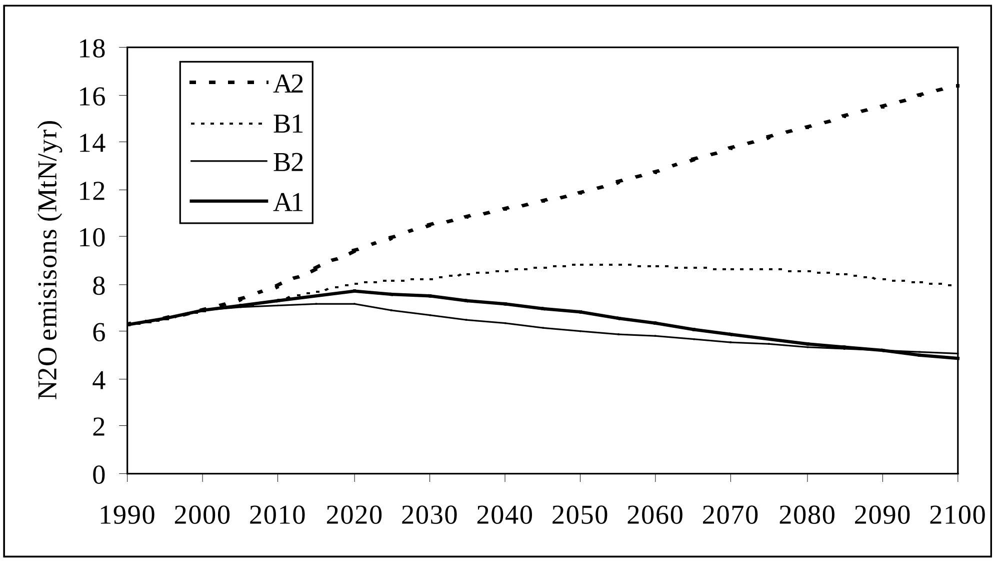

Figure 4. Global anthropogenic N_2O emissions, MtN per year.

The A2 scenario shows increasing anthropogenic emissions of N_2O according to Figure 4, reaching a level of 16.3 MtN/yr within year 2100. The natural emissions of N_2O are 9 MtN/yr (IPCC, 1999). The B2 and A1 scenario show a continued increase in N_2O emissions until year 2010 and 2020 respectively, but beyond this time period a trend of decreasing emission levels appears. In year 2100 the emission level in both scenarios is below present level of emissions.

In the case of N_2O emissions there are large differences in range between the new and old scenarios. The IS92 emission scenarios range from 13.7 to 19.1 MtN/yr in 2100. The SRES scenarios range from 4.9 to 16.4 MtN/yr. Contrary to the CO_2 and CH_4 emission profiles the new scenarios show a larger range of N_2O emissions than the old scenarios.

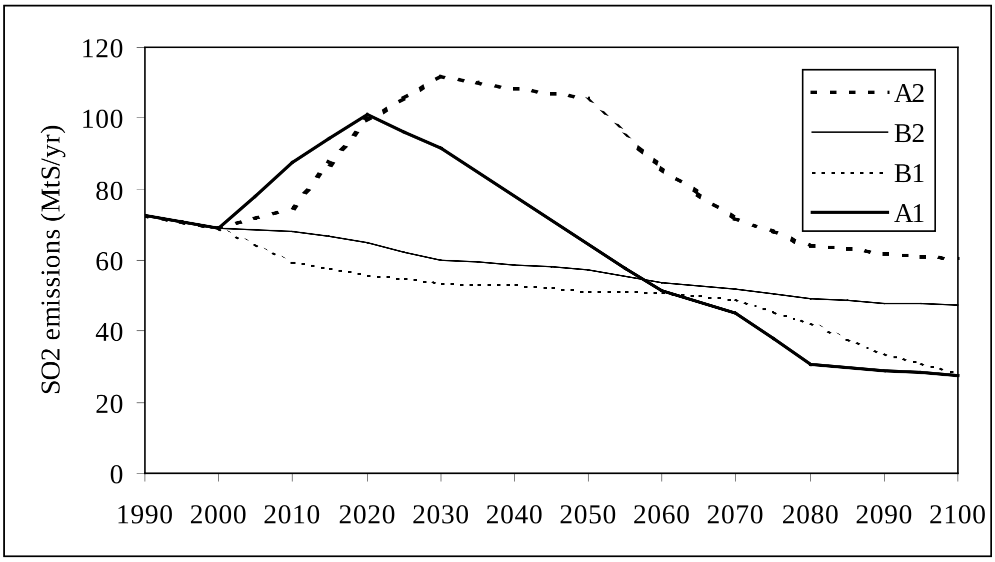

Figure 5. Global anthropogenic SO_2 emissions, MtS per year.

In Figure 5 all SRES emission scenarios show a decline in anthropogenic SO_2 emissions from 1990 till 2000 of about 3.5 MtS/yr. The A2 scenario shows fairly high emissions for the next decades reaching a maximum at 112 MtS/yr in 2030. Beyond this time period, SO_2 emissions are declining. The A1 scenario shows a similar trend, but has an even more dramatic decrease in emissions and eventually reaches a level of 27.4 MtS/yr, which are far below present emission levels (69 MtS/yr).

Perhaps the most striking difference between the IS92 scenarios and the SRES scenarios is the change in the development of SO_2 emissions. Compared to the IS92 scenario the new set of IPCC scenarios has significantly lower SO_2 emissions. In the IS92 scenarios the SO_2 emissions range from 77 to 254 MtS/yr in 2100. Both the level and the range are dramatically reduced in the SRES scenarios with a low SO_2 emission estimate of 24.4 and a high of 60.3 MtS/yr. Less consumption of SO_2 intensive, fossil fuel together with the introduction of clean technology explain the decline in emissions. The expected reductions are foremost motivated on the ground of local and regional pollution problems.

Among the future emissions of the 29 components, 3 gases (HCFC-124, HCFC-225ca and HCFC-225cb) are not presented in the IPCC Special Report, and data from IPCC (1992) is used.

Due to limitations in our understanding of the sources, sinks and possible chemical transformation for many of the major greenhouse gases, together with simplifications within the model structure, there is attached considerable uncertainty to the results. Gases with lifetimes longer than about two years are well mixed globally. Thus, the effects of most of the climate gases are independent of the location of the sources. This is not the case for SO_2 emissions. Emissions of SO_2 have a cooling effect on a regional scale. The geographical distribution of SO_2 emissions is not accounted for in the model.

4 Concentrations

The atmospheric concentration of CO_2 is calculated on the basis of work published by Joos et al. (1996). The parameterisation is founded on a complex model for the carbon cycle where the exchange of carbon between the atmosphere, the biosphere and the oceans is considered. Future concentrations of other gases are calculated by standard equations based on emissions and chemical decay of the different gases in the atmosphere. For more details on the modelling of concentrations see Fuglestvedt and Berntsen (1999) and Alfsen and Berntsen (1999).

Concentration levels for the most important greenhouse gasses are presented in the following graphs. The SO_2 concentration levels are not included in this section since radiative forcing from sulphate (direct and indirect effects) is calculated directly from SO_2 emissions.

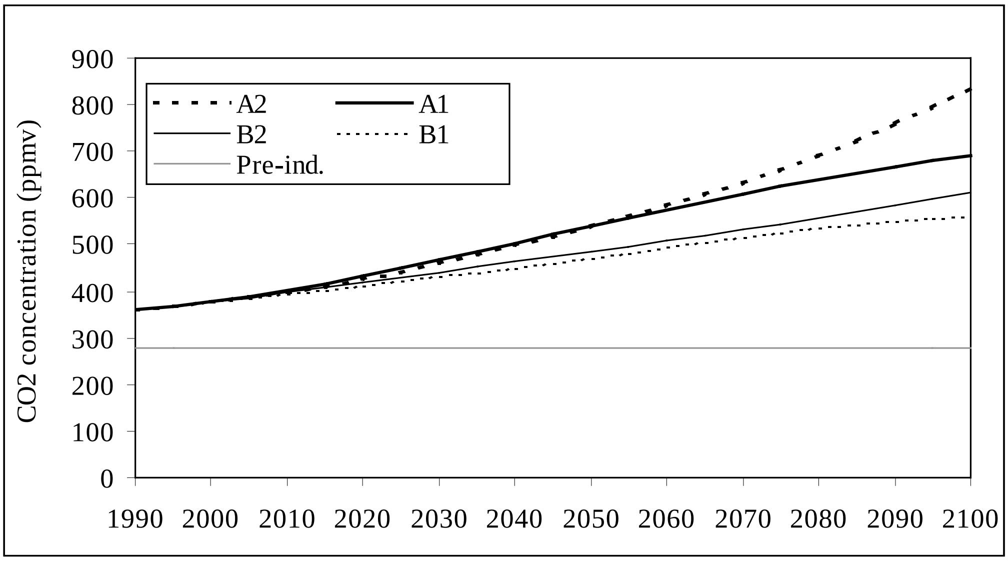

Figure 6. Modelled CO_2 concentrations in the A1, A2, B1 and B2 scenarios.

Figure 6 shows the modelled future concentrations of CO_2 for the SRES emission scenarios. By the end of the century the CO_2 concentration in the atmosphere has reached 800 parts per million by volume (ppmv) in the A2 scenario. The other scenarios range from a minimum of 550 ppmv (B1) to almost 700 ppmv in the A1 scenario.

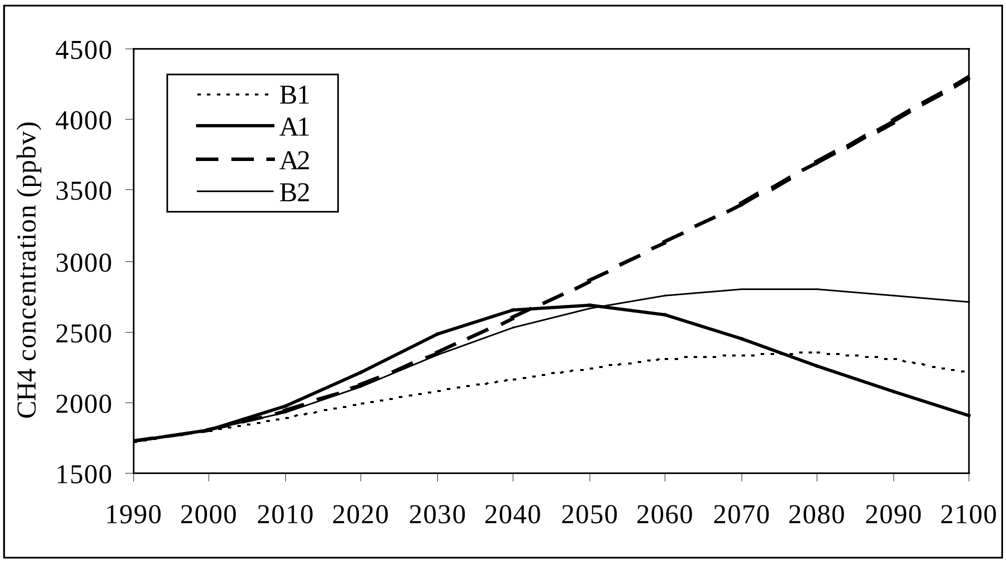

Figure 7. Modelled CH_4 concentrations in the A1, A2, B1 and B2 scenarios.

CH_4 concentrations are calculated on the basis of the anthropogenic emissions of CH_4 as displayed in Figure 3, together with a constant natural component of 160 MtCH_4/yr (IPCC, 1999). In comparison the pre-industrial level of CH_4 concentrations was 700 ppbv (IPCC, 1996). Figure 7 shows that the modelled CH_4 concentrations are expected to increase significantly in the A2 scenario. The A1 and B2 scenarios follow this trend of increased levels of CH_4 concentration in the first half of the century. Thereafter, the A1 scenario shows a decreasing CH_4 concentration profile and concentrations in the B2 scenario seems to levels off. The B1 scenario has generally a lower concentration profile until 2075. In year 2100 the CH_4 concentrations are modelled to range from a high estimate of 4200 parts per billion by volume (ppbv) in the A2 scenario and a low estimate of 1800 ppbv in the B2 scenario.

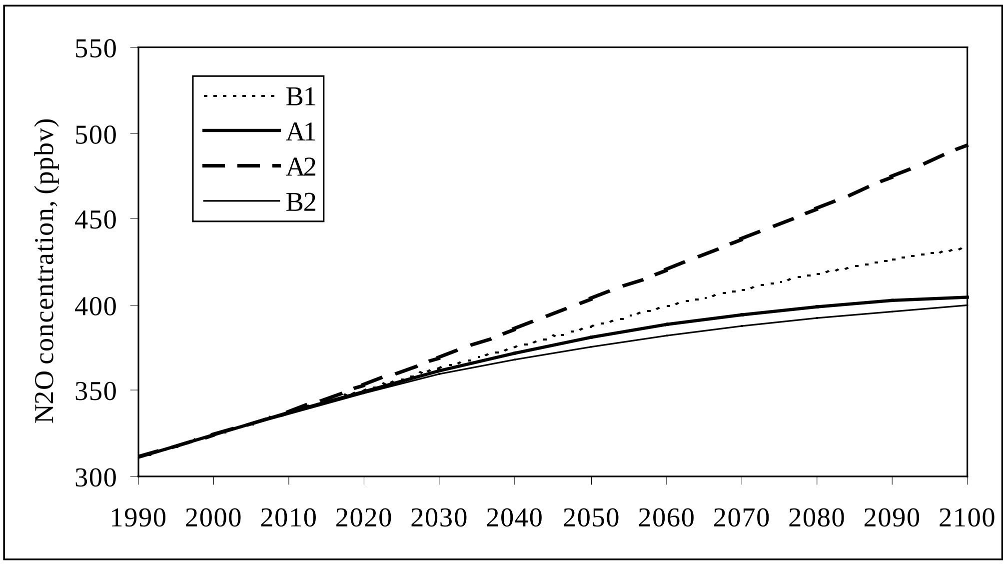

Figure 8: Modelled N_2O concentrations in the A1, A2, B1 and B2 scenarios.

In addition to the anthropogenic emissions of N_2O, a constant natural contribution of 9 MtN/yr is incorporated when concentrations are estimated (IPCC, 1999). Beyond year 2020 the modelled future concentrations of N_2O have diverging trajectories (Figure 8). The A2 scenario gives a N_2O concentration level of 490 ppbv in 2100 and the concentration in the B2 and A1 scenarios reach approximately 400 ppbv. The pre-industrial concentration level for N_2O was 275 ppbv (IPCC, 1996).

Similar to the IS92 scenarios, the SRES scenarios imply increasing concentration in all greenhouse gases from 1990 to 2100. This does not include ozone-depleting gasses regulated in the Montreal Protocol. These gasses show a decreasing emission profile.

5 Radiative forcing

Radiative forcing from the modelled concentrations in source gases is calculated by applying standard parameterisations published in the literature (WMO, 1999; Wigley, 1998; Myhre et al., 1998; IPCC, 1996; Wigley and Reeves, 1991). In addition, radiative forcing is calculated for soot and sulphate aerosols (direct and indirect effects) as well as the secondary components tropospheric and stratospheric ozone and stratospheric water vapour.

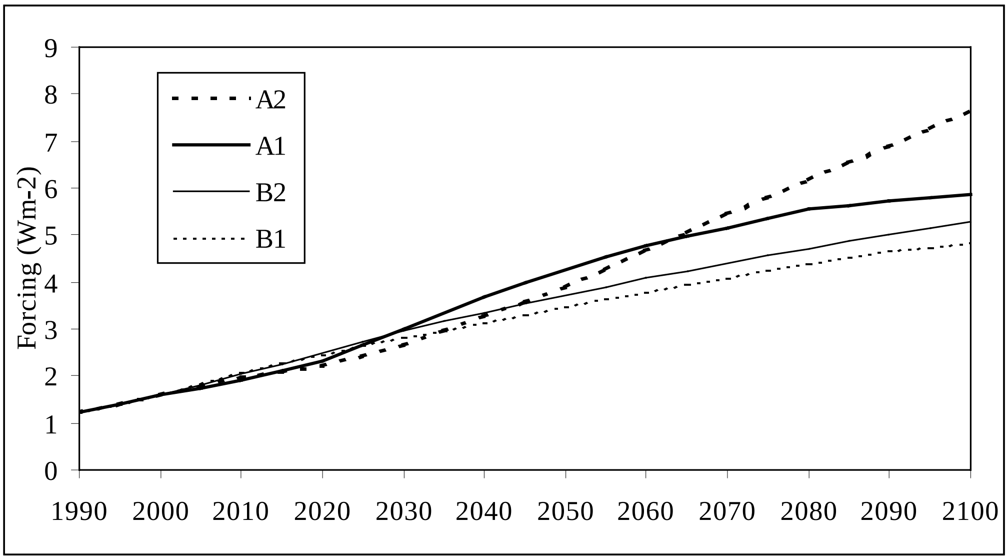

Figure 9: Modelled total forcing in the in the A1, A2, B1 and B2 scenarios.

The total radiative forcing calculated in the A1, A2, B1 and B2 scenarios are shown in Figure 9. The scenarios imply increased forcing in the future. The forcing is calculated to range from 4.8 to 7.5 W/m^2 by the end of the century. In comparison, the IS92 scenarios had a range of approximately 4 to 8 W/m^2 as shown in Figure 10. As mentioned earlier, the new model calculations for the SRES scenarios also take into account updated model parameters, which include CO_2, N_2O and new lifetimes given in WMO 1999. In IS92a this implying reduced forcing from CO_2 and N_2O by 0.91 and 0.08 Wm^2 in 2100, respectively. Due to this reduced forcing the temperature change for IS92a is reduced by 0.34 °C in 2100.

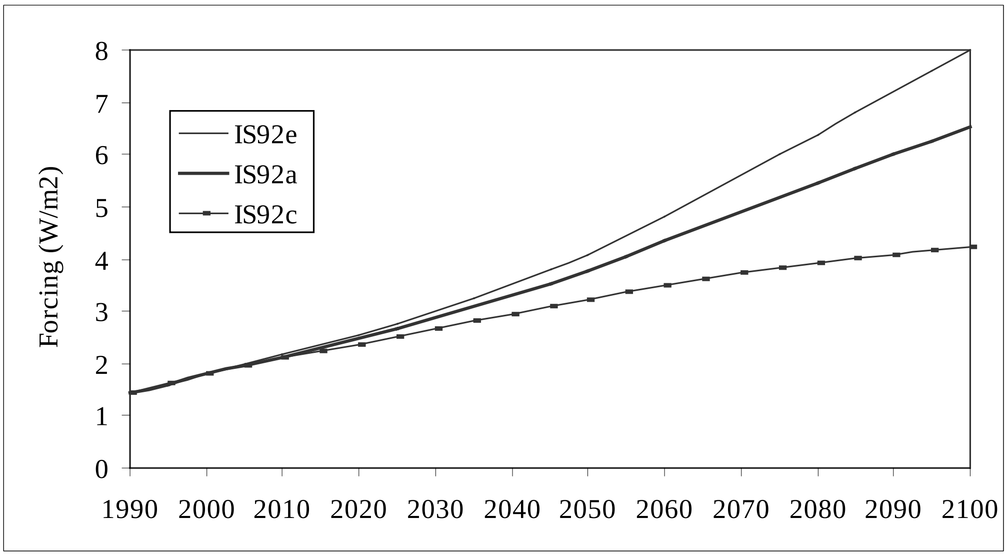

Figure 10. Total forcing in the IS92e, IS92a and IS92c scenarios (Fuglestvedt and Berntsen, 1999).

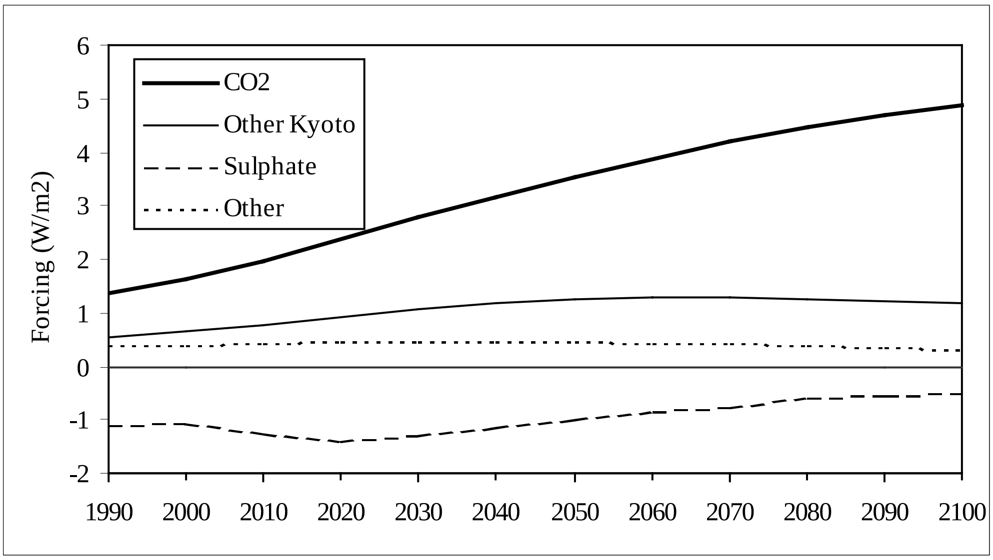

Figure 11. Estimated forcing from main components in the A1 emission scenario (W/m^2).

Figure 11 shows the future radiative forcing for CO_2, other greenhouse gases included in the Kyoto Protocol, sulphate formed from SO_2 emissions (direct and indirect effects) and other greenhouse gases, for the A1 emission scenario. The increasing radiative forcing profile in the A1 scenario (Figure 9) is largely dominated by the forcing generated from CO_2 emissions. CO_2 shows a forcing close to 5 W/m^2 by the end of the century. The model includes both the direct effects of sulphate aerosols scattering of solar radiation and the indirect effect of these aerosol levels on the distribution and properties of clouds. Both these effects result in negative forcing. The reduced negative forcing from sulfate aerosols enhance the increase in radiative forcing.

6 Temperature and sea level changes

The estimated radiative forcing serves as input to an energy-balance-climate/upwelling-diffusion-ocean model developed by Schlesinger et al. (1992). The global and hemispherical change in annual mean temperature and sea level rise are calculated based on the exchange of energy between the atmosphere and the ocean, and the transport of energy in the ocean. The change in sea level is both determined by the melting of glaciers and the thermal expansion of water. The model is similar to those applied by IPCC for scenario studies (IPCC, 1996; IPCC, 1997; Wigley and Raper, 1992).

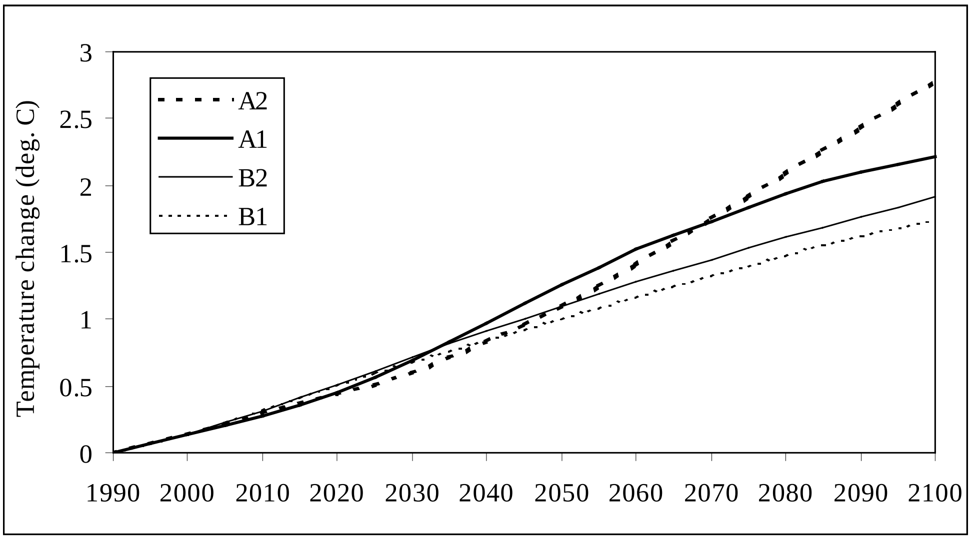

Figure 12. Modelled temperature change relative to 1990 in the A1, A2, B1 and B2 scenarios with a climate sensitivity of 2.5 °C for 2 x CO_2.

The calculated changes in global mean temperature relative to 1990 for the three scenarios are shown in Figure 12. The A2 scenario gives a warming of 2.8 °C in year 2100, while the other scenarios show a more modest temperature change ranging from 1.7 °C to 2.1 °C by the end of the century.

The modelled temperature change in the IS92 scenarios is shown in Figure 13. The range between high and low temperature change is larger than in the SRES scenarios.

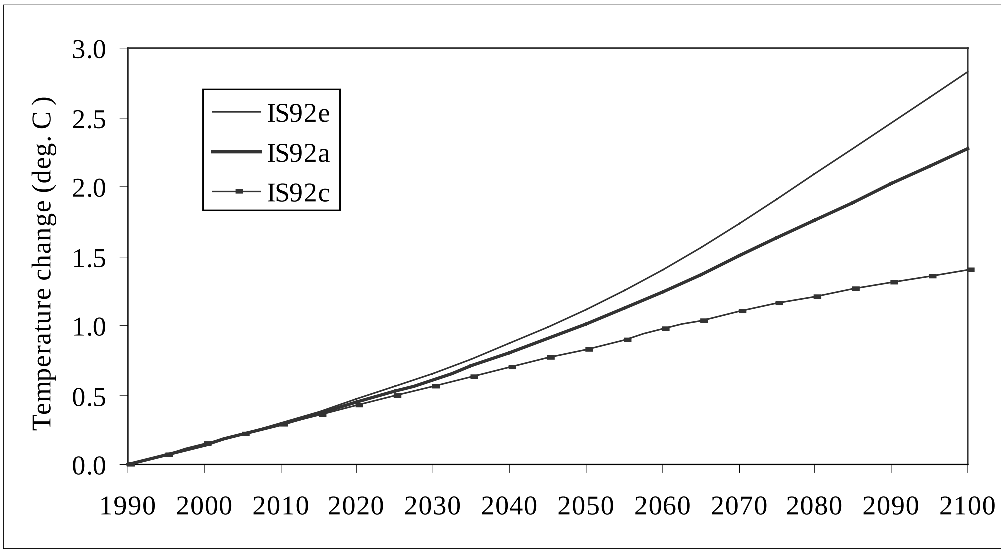

Figure 13. Modelled temperature change relative to 1990 in the IS92e, IS92a and IS92c scenarios with a climate sensitivity of 2.5 ^{o}C for 2 x CO_2 (Fuglestvedt and Berntsen, 1999).

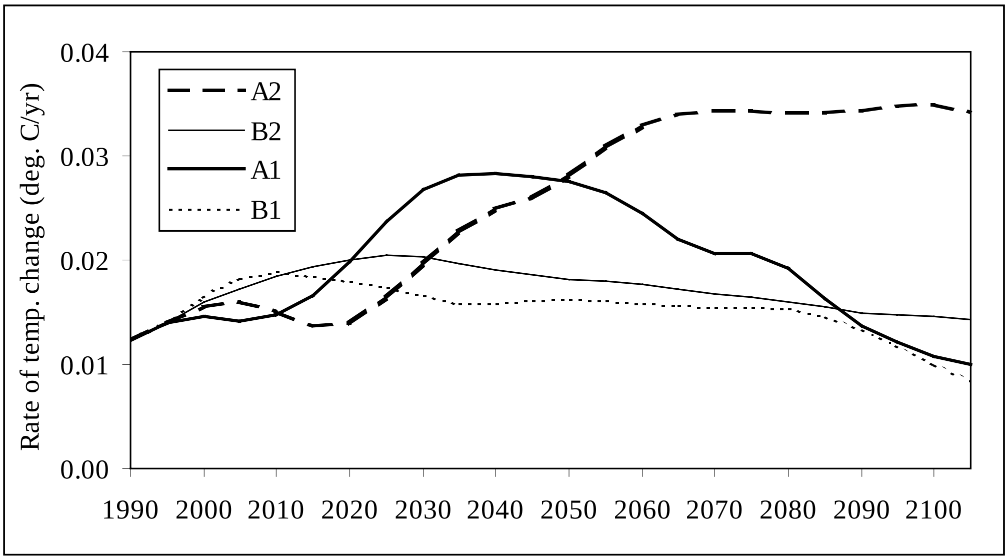

Figure 14. Modelled rate of temperature change in the A1, A2, B1 and B2 scenarios with a climate sensitivity of 2.5 ^{o}C for 2 x CO_2.

With respect to impact of climate change the rate of temperature change (dT/dt) may be of larger importance than the eventual level of temperature change. Figure 14 shows the rate of temperature change by each scenario. The A1 and A2 scenario shows rather variable rate of temperature change contrary to the B1 and B2 scenario. By the end of the century the rate of change in the A2 scenario is modelled to level off at 0.035 ^{o}C/yr. The A1 scenario reaches a maximum in year 2040 at 0.029 ^{o}C/yr, thereafter the rate of temperature change declines gradually. The B1 and B2 scenarios show moderate rate of temperature change until 2100.

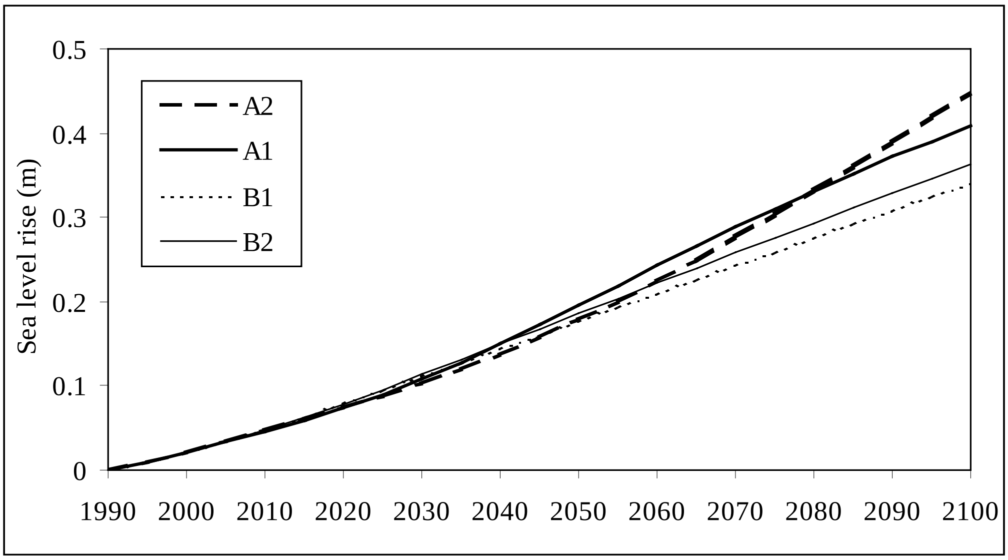

Figure 15. Modelled sea level rise relative to 1990 for the A1, A2, B1 and B2 scenarios.

The calculated changes in sea level relative to 1990 for the SRES scenarios are shown in Figure 15. The sea level rise estimates from 1990 to 2000 ranges between 0.33 and 0.45 meter. The range in modelled sea level rise is not as large as in the case for temperature change. The rather narrow sets of profiles reflect the long lag between CO_2 emissions changes and their effect on climate. Sea level rise this century is determined by emissions already undertaken due to this lag in the system.

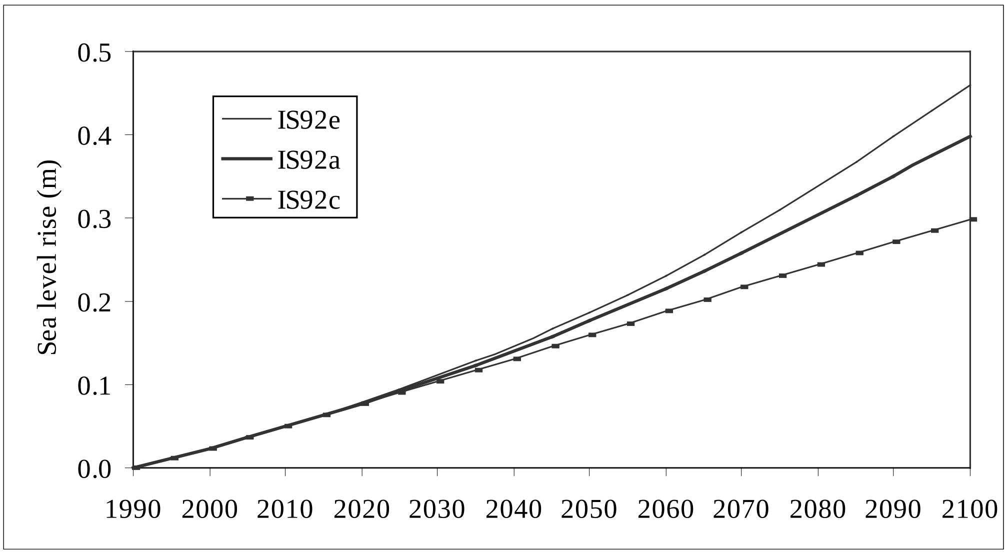

Figure 16. Modelled sea level rise relative to 1990 for the IS92e, IS92a and IS92c scenarios (Fuglestvedt and Berntsen, 1999).

Estimated sea level rise using the IS92 scenarios give a larger range of values than in the new SRES scenarios according to Figure 16.

7 Climate sensitivity

The future emission of climate gases is one of the main uncertainties in predictions of future man-made climate change. In addition, the sensitivity of the climate system to radiative forcing is uncertain (see footnote 1, page 5). This sensitivity reflects the strengths of the feedback processes in the climate system. Climate sensitivity can not be estimated by a SCM, but must be prescribed based on studies with GCMs or paleo climate studies.

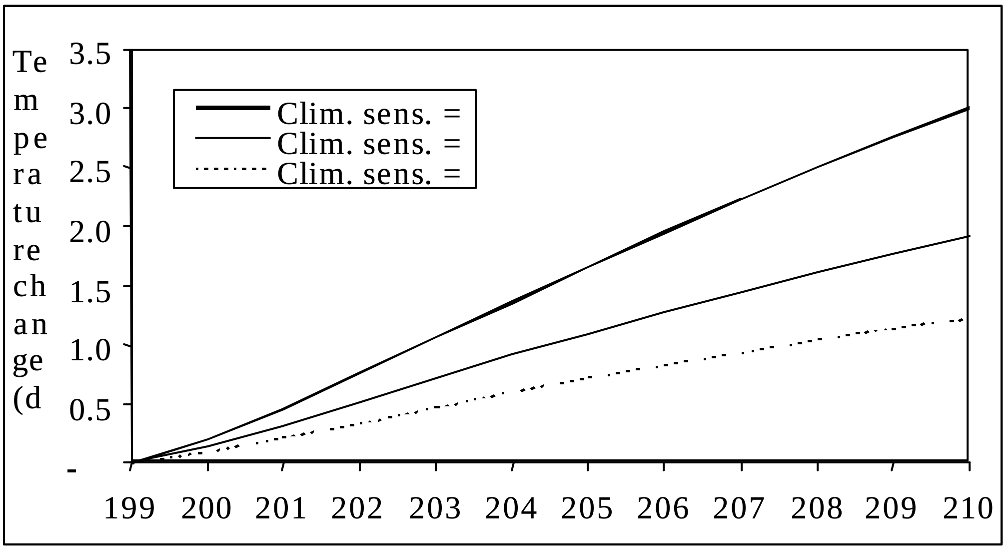

Figure 17. Temperature changes in B2 with various climate sensitivities.

Figure 17 shows the future warming based on the B1 scenario for the prescribed sensitivities 1.5, 2.5 and 4.5 ?C for 2 x CO_2. A low sensitivity gives a temperature change of 1.2?C in 2100 compared to 1990. Assuming a climate system with high sensitivity (4.5 ?C) the modelled warming reaches 3.0 ?C.

8 Comparison of the B2 scenario and the IS92a scenario

In this section we will present a comparison of the modelled output based on the SRES scenarios with output modelled on the basis of the IS92 scenarios. Generally we find lower emissions in the SRES scenarios compared to emission levels in the IS92 scenarios. We use the B2 scenario and IS92a scenario for comparison purposes.

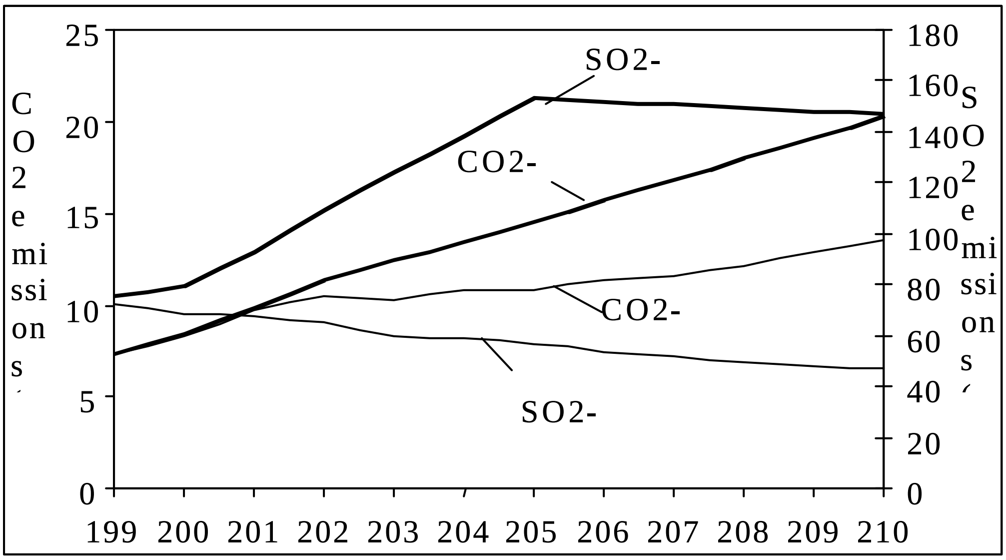

Figure 18. SO_2 and CO_2 emissions in IS92a and B2 scenario measured in billion ton carbon (GtC) and million tons sulphur (MtS) per year respectively.

Figure 18 compares the CO_2 and the SO_2 emission trajectories from the B2 scenario with that of the IS92a scenario. In the case of CO_2 emissions, the different scenarios show similar emission trends until the year 2010. Thereafter the B2 scenario shows lower emission levels than the IS92a scenario. In 2100 the B2 scenario show emissions of 13,5 GtC/yr and IS92a reaches 20 GtC/yr. SO_2 emissions show very different trends in the two scenarios. The B2 scenario shows continuously decreasing SO_2 emissions throughout the century reaching 47 MtS/yr in 2100. In the IS92a scenario the emissions of SO_2 increase to 153 MtS/yr within year 2050 and thereafter slowly decreases to a level of 147 MtS/yr in 2100.

The radiative forcing due to the reduced CO_2 emissions in the B2 scenario compared to emissions in the IS92a scenario is shown in Figure 19. For CO_2 the modelled radiative forcing in the B2 scenario is below that of the IS92a scenario from about year 2020 until the end of the century[2].

[2] The comparison of the IS92a scenario and the B2 scenario in Figure 19 is based on updated forcing parameters for CO_2 and N_2O as well as updated lifetimes for several gases according to WMO (1999).

The figure also illustrates the difference in radiative forcing between the two scenarios with respect to other gases. "Other" gases include *i*) gases in the Kyoto Protocol such as CO_2, CH_4, N_2O, PFC, HFC and SF_6 and *ii*) 19 gases not included in the Protocol. The two scenarios show similar trends in radiative forcing until the middle of this century. Diverging profiles are modelled thereafter with the B2 scenario levelling off.

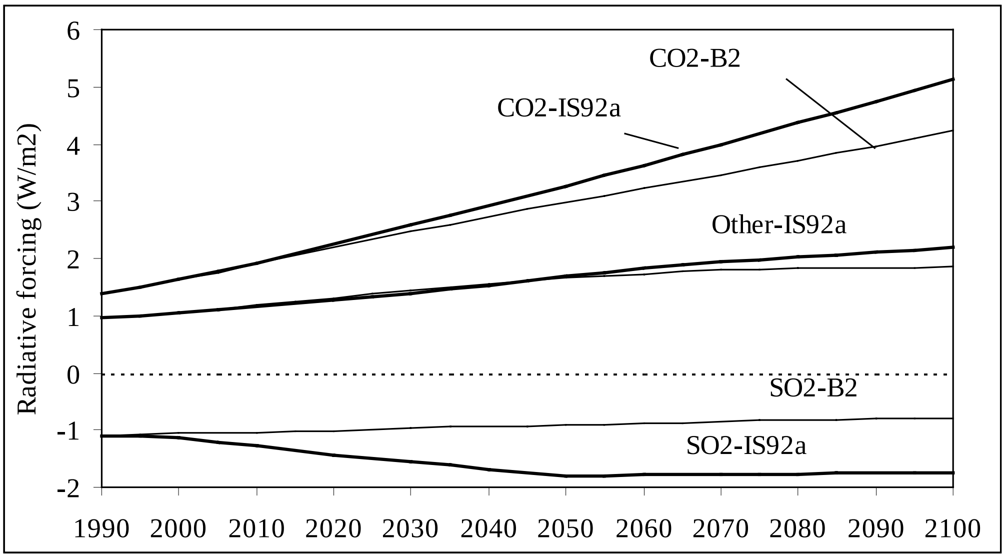

Figure 19. Modelled future radiative forcing from different gas emissions in the IS92a and the B2 scenario.

The most pronounced difference between the two scenarios is found in the modelled radiative forcing from SO_2 emissions. Less SO_2 emissions in the B2 scenario results in a smaller cooling effect than in the IS92a scenario.

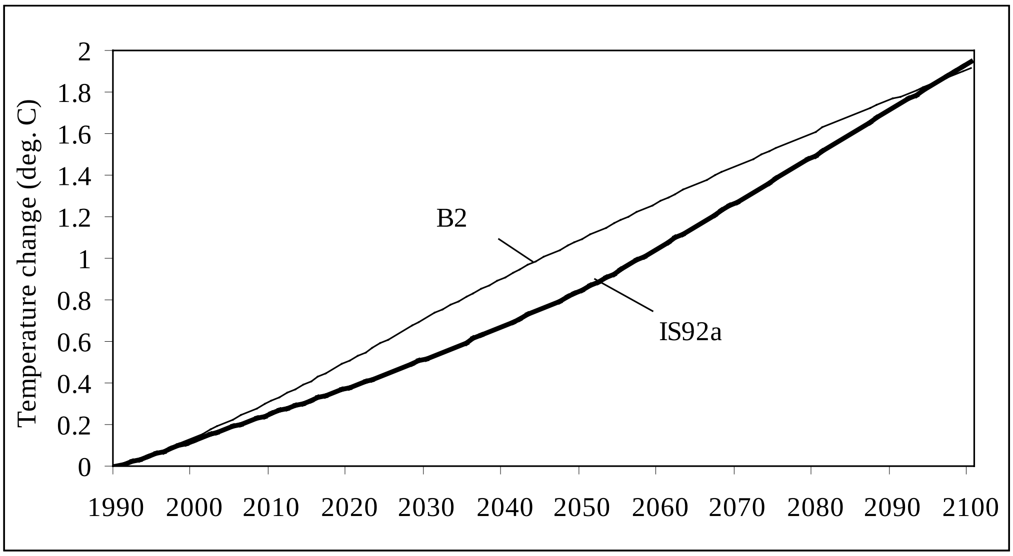

Figure 20. Modelled temperature change relative to 1990 levels in the IS92a and B2 scenario.

Figure 20 shows that the B2 scenario results in higher temperatures than the IS92a scenario during this century, but that the IS92a scenario intersects the B2 trajectory within 2100. The low SO_2 emissions in the B2 scenario results in a reduced global cooling outweighing the effects of less CO_2 emissions in the short run. Near the end of the century this is changing, as the effect of reduced CO_2 emissions in the B2 scenario finally reverses the trend, resulting in less temperature increase.

9 Conclusion

The preliminary scenarios presented in the Special Report from IPCC build on another methodology and quit different assumptions than the IS92 scenarios from 1992 (IPCC, 1992). The difference is reflected in the greenhouse gas emission trajectories in the four marker scenarios. The four markers present a summary of what are thought to be possible emission levels throughout this century for the main greenhouse gases. According to the comparison of these marker scenarios and the IS92 scenarios the former generally suggests emission levels around present levels or even lower by the end of the century in contrast to the IS92 scenarios. It is still important to recognise the large range of emission profiles within the 40 different scenarios on which the markers are based. This range is much larger than that of the IS92 scenarios reflecting large uncertainties regarding future emissions.

For comparison reasons we have in Figure 21 included an overview of the modelled results based on the emission trajectories in SRES scenarios and that of the IS92 scenarios (Fuglestvedt and Berntsen, 1999) for the year 2100.

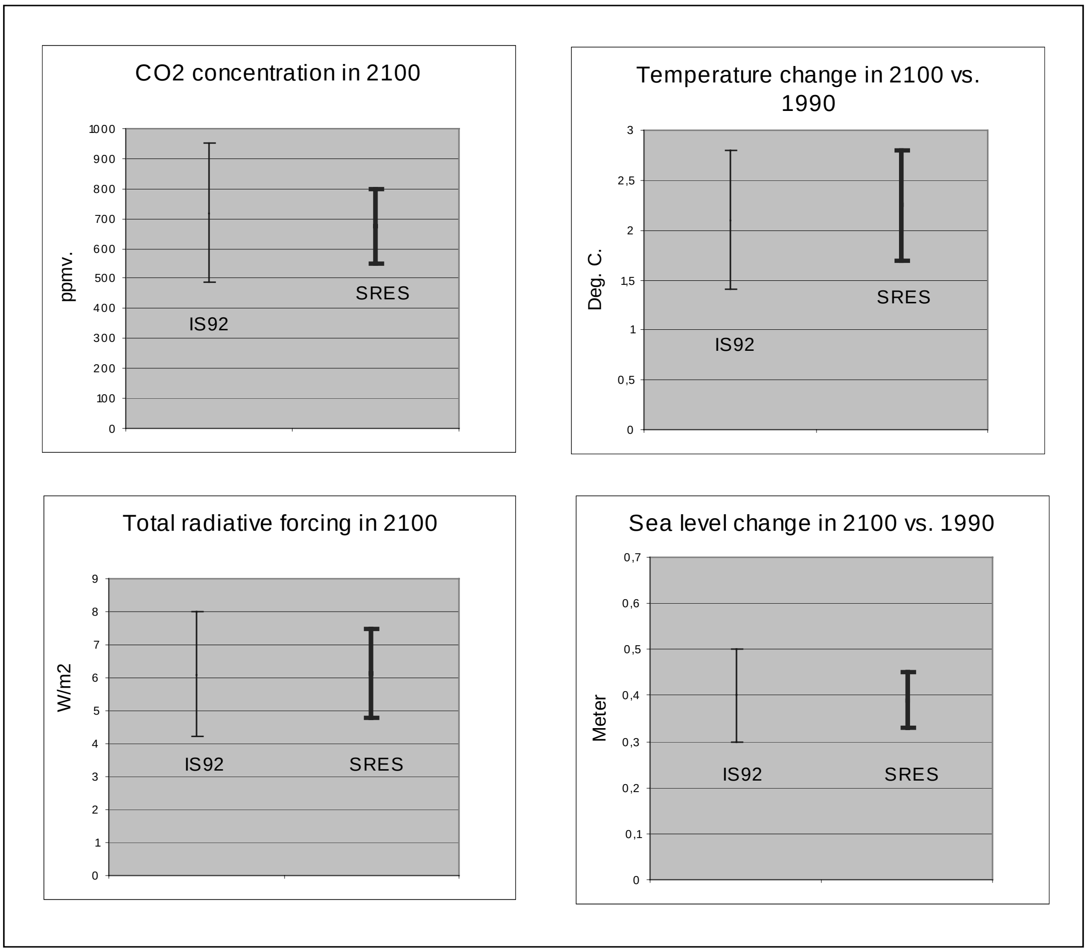

Figure 21: Comparing the old IS92 scenarios with the new preliminary SRES scenarios with respect to the range of a) CO_2 concentration level; b) total forcing in 2100; c) temperature change in year 2100 compared to 1990 with a climate sensitivity of 2.5 °C; d) sea level rise in year 2100 compared to 1990 with a climate sensitivity of 2.5 °C.

Compared to the modelled CO_2 concentration levels based on the old IS92 scenarios the SRES scenarios show a much more narrow range of concentration estimates. The new concentration estimates range from 550 ppmv to about 800 ppmv in 2100. Estimates based on the IS92 scenarios show a range from 490 to 950 ppmv (Fuglestvedt and Berntsen, 1999). Also the other greenhouse gases included in the Kyoto Protocol generally show a more narrow range in the new scenarios with respect to concentration levels.

The marker scenarios in SRES show emission trajectories more modest in range than the old IS92 scenarios. This has consequences for modelled radiative forcing, temperature change and sea level rise. The radiative forcing based on the IS92 scenarios shows a larger range than the SRES marker scenarios. This is due to new emission scenarios, mainly for CO_2 and SO_2, and updated parameters within the model. The difference in temperature change and sea level rise is not that profound, but a slightly narrower rage is observed in the marker scenarios.

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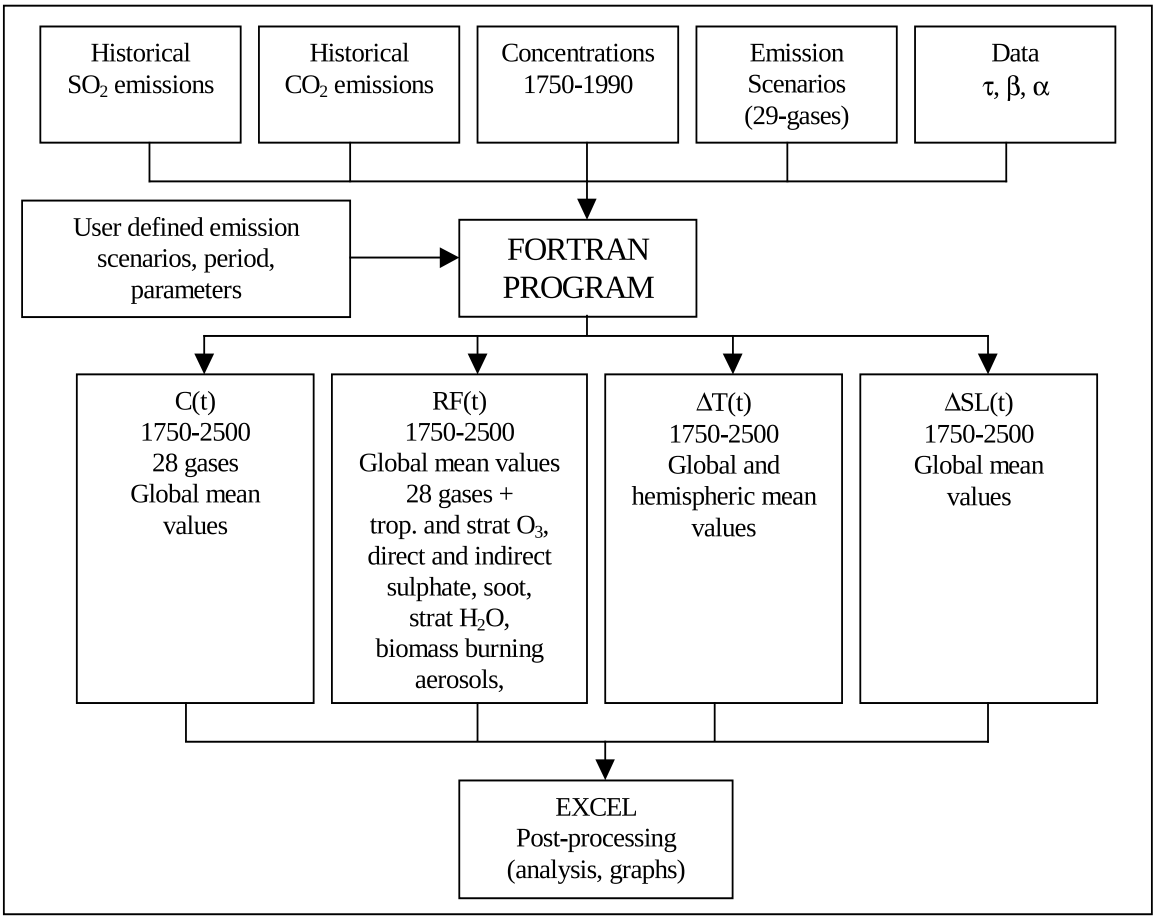
Appendix:

I) Source gases included in the simple climate model:

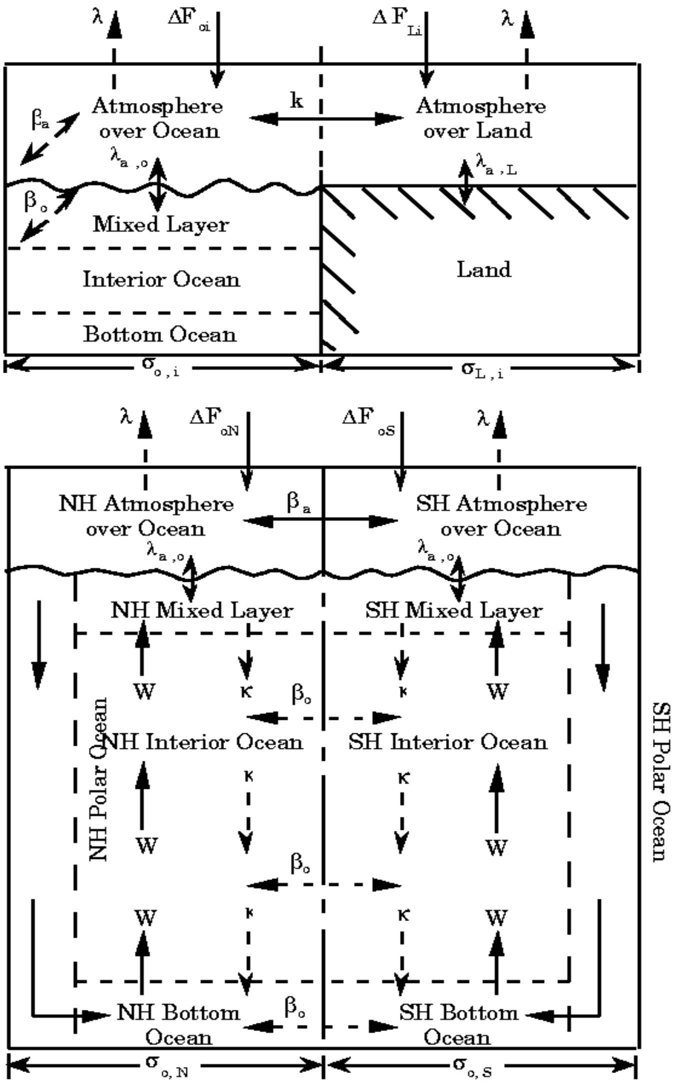
CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous oxide
SO_2	Sulphur dioxide
CCl_3F	CFC-11
CCl_2F_2	CFC-12
CCl_2FCClF_2	CFC-113
$CClF_2CClF_2$	CFC-114
CF_3CClF_2	CFC-115
$CHClF_2$	HCFC-22
CF_3CHCl_2	HCFC-123
CF_3CHClF	HCFC-124
CH_3CFCl_2	HCFC-141b
CH_3CF_2Cl	HCFC-142b
$C_3HF_5Cl_2$	HCFC-225ca
$C_3HF_5Cl_2$	HCFC-225cb
CCl_4	Carbon tetrachloride
CH_3CCl_3	Methylchloroform
C_2HF_5	HFC-125
CH_2FCF_3	HFC-134a
CH_3CHF_2	HFC-152a
CHF_3	HFC-23
$CBrClF_2$	H-1211
$CBrF_3$	H-1301
$CBrF_2CBrF_2$	H-2402
CH_3Br	Methylbromide
CF_4	Perfluoromethane
C_2F_6	Perfluoroethane
SF_6	Sulphur hexafluoride

II) The file structure of the simple climate model:



τ: Atmospheric lifetime, β: conversion factor, α: radiative parameters

III) The energy-balance-climate/upwelling-diffusion-ocean model developed by Micheal E. Schlesinger (Schlesinger et al., 1992):



Schematic diagram of the simple climate/ocean model. The top panel shows the general structure of the model, and the bottom panel shows a vertical cross-section through the oceanic part. The symbols by the arrows indicate the following physical processes; ΔF_{Li} and ΔF_{oi}: tropopause radiative forcing in hemisphere i over land and ocean, respectively; λ: radiative-plus-feedback temperature response of the climate system; k: atmospheric land-ocean heat exchange; β_a atmospheric interhemispheric heat exchange; $\lambda_{a,o}$: air-sea heat exchange; $\lambda_{a,L}$: air-land heat exchange; β_o : oceanic interhemispheric heat exchange; W: vertical heat transport by upwelling; κ:vertical heat transport by diffusion. The quantities $\sigma_{o,i}$ and $\sigma_{o,i}$ denote the fractions of hemisphere i covered by land and ocean, respectively (Schlesinger et al., 1992).

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