ANNEX

Climatic consequences of emissions and a comparison of IS92a and SA90

J.F.B. Mitchell; J.M. Gregory

Annex

For the 1990 IPCC Scientific Assessment (IPCC, 1990), IPCC Working Group III developed four scenarios of future emissions of greenhouse gases. These were used by Working Group I to produce estimates of the resulting rate and magnitude of climate change, represented by the global average surface temperature. In the current report, six revised emissions scenarios (referred to as IS92a-f) have been described (see Section A3). The purpose of this Annex is to present calculations of the temperature rise consequent on these new scenarios and to compare IS92a with the IPCC 1990 Scenario A (SA90) using the same assumptions as those used in IPCC (1990).

The calculations are performed using a one-dimensional climate model and a series of gas cycle models that relate emissions to concentration changes (STUGE, Wigley *et al.*, 1991). The climate model is essentially the same as the model used by IPCC (1990) and it reproduces their results well. For instance, using SA90 with a climate sensitivity of 2.5°C, IPCC 1990 found a warming of 3.3°C over the period 1990-2100 (see IPCC, 1990, Figure A.9). For the same scenario, the model gives the same figure to within 0.1°C. The gas cycle models simulate well the IPCC (1990) concentration projections (which were obtained by averaging the results from a number of different models) for the full range of emission scenarios considered by IPCC (1990).

The inputs to the model are the projected emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the halocarbons CFC-11, CFC-12 and HCFC-22. CO_2 emissions are converted to concentrations using a simple carbon cycle model, developed by parametrizing results from an ocean circulation model including a carbon cycle. CH_4 concentrations are obtained from a mass balance with exponential decay terms representing atmospheric destruction and the soil sink. The lifetime for the former process is made to depend on CH_4 concentration and CO_2 emissions. N_2O and halocarbons, however, are treated as having constant decay times. Note that we have not updated the atmospheric lifetimes of CFC-11 (65 years), CFC-12 (130 years) and CH_4 to the later estimates given in Section A3.

The time-series of atmospheric concentration of the various gases are used to calculate the resulting changes in radiative forcing, following Table 2.2 of IPCC (1990). Halocarbons, other than the three named above, are not handled directly by the model, but are accounted for by scaling up, by a factor of 1.43, the combined effects of CFC-11 and CFC-12. The direct radiative effect of the CH_4 concentration is also inflated, by a factor of 1.3, in order to represent the effect of stratospheric water vapour produced by oxidation of methane. No account is taken of the influence of ozone or sulphate aerosols.

The time-series of radiative forcing is then applied to an upwelling-diffusion energy-balance climate model. Essentially, this comprises an oceanic mixed-layer coupled to a vertical water column in which heat is transported by diffusion and advection. The model is one-dimensional, but the presence of land masses is accounted for by having separate, zero-heat-capacity boxes for land in each hemisphere. The response of the climate system to the changes in radiative forcing is principally determined by the climate sensitivity, normally quoted as the equilibrium global mean temperature change expected for a doubling of atmospheric CO_2. In the model, this parameter accounts for all ways in which the mixed-layer loses heat except for the flux into the deep ocean. Climate feedbacks are not explicitly modelled but their effects are accounted for by the choice of a range of values of the climate sensitivity. Three different values were used, namely 1.5°C, 2.5°C (the IPCC (1990) "best-estimate") and 4.5°C. For these and the other parameters of the model (depth of the mixed-layer, ocean thermal diffusivity, rate of upwelling and temperature response of polar sinking water) the same values were chosen as in IPCC (1990).

Two points should be noted concerning the emissions scenarios as they are entered into the model. Firstly, the model fixes the 1990 emissions in each case to accord with the values used in IPCC (1990) . These figures do not agree with those in IS92; this causes an inevitable discrepancy between the intended emissions and the figures actually used for 1990-1995 (for the halocarbons) or 1990-2000 (for the other gases). Secondly, the current version of the model requires scenarios to be specified as figures at a certain number of fixed times, and linear interpolation is performed between them. Thus the points used by the model do not all correspond to those used in the scenarios, leading to small differences in some cases because of discrepancies in the periods of linear interpolation.

The largest radiative forcing is produced by IS92e and f (Figure Ax.1). CFCs are phased out more rapidly in IS92e, giving slightly less forcing early in the century, but larger increases in CO_2 emissions later on result in larger forcing in IS92e. Of the middle scenarios (IS92a and b), IS92a has slightly greater CO_2 emissions, while CFCs are phased out faster in IS92b, so the forcing is larger in IS92a throughout. In the low scenarios (IS92c and d), CFCs are phased out rapidly in IS92d early on, giving smaller forcing, but large reductions in CO_2 emissions in IS92c later on reverse the order of the magnitudes of forcing in the latter half of the century.

Using the "best-estimate" sensitivity, these scenarios give a range of warming from 1.5 to 3.5°C by the year 2100 (Figure Ax.2). Also shown are the warmings with low, best-estimate and high climate sensitivities for IS92a which give warmings of 2 to 4°C over the next hundred years (Figure Ax.3).

It is also instructive to compare IS92a with SA90. The concentrations of CO_2 and N_2O are similar (Figures Ax.4 and Ax.5) but CH_4 concentrations are slightly higher in the 1990 Scenario. The difference in forcing due to these gases is about 0.4Wm^{-2} (Figure Ax.6). However, the concentrations of HCFC grow much more rapidly in the SA90 case, and the concentrations of CFCs increase whereas in IS92a they decrease (Figure Ax.7) giving a difference of about 0.7Wm^{-2} in radiative forcing (Figure Ax.8). Thus the forcing is about 15% less in IS92a (Figure Ax.9), giving a slightly smaller warming (Figure Ax.10).

References:

IPCC, 1990: *Climate Change: The IPCC Scientific Assessment.* J.T. Houghton, G.J. Jenkins and J.J. Ephraums (Eds.). Cambridge University Press, Cambridge, UK, 365pp.

Wigley, T.M.L., T. Holt and S.C.B. Raper, 1991: STUGE (An Interactive Greenhouse Model): User's Manual. Climatic Research Unit, Norwich, UK, 44pp.

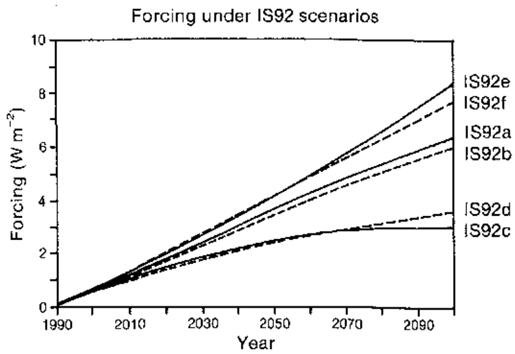

Figure Ax.1: Changes (post-1990) in radiative forcing (Wm^{-2}) arising from scenarios IS92a-f derived from the model of Wigley *et al.* (1991). IS92a, c and e are shown as solid curves; b, d and f are shown as dashed. No allowance has been made for changes in ozone or for the effects of increases in sulphate aerosol.

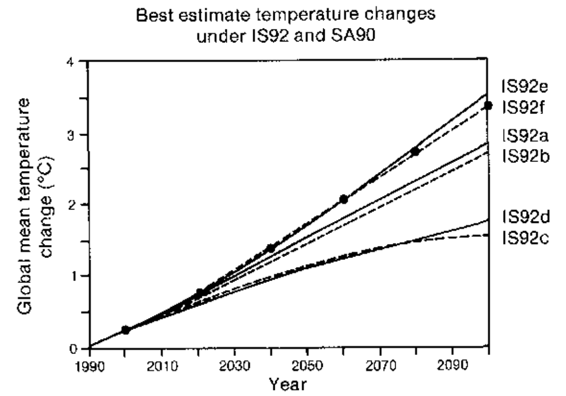

Figure Ax.3: As for Figure Ax.1 but for temperature change (°C) assuming a "Best-estimate" climate sensitivity of 2.5°C. The changes due to SA90 are shown as solid circles.

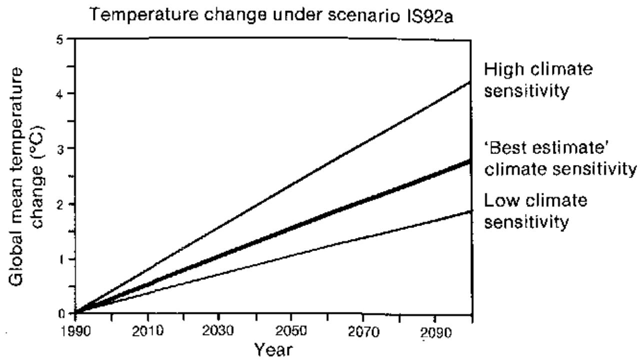

Figure Ax.2: Simulated changes in global mean temperature after 1990 under IS92a due to doubling CO_2, assuming High, "Best-estimate" and Low climate sensitivities (4.5, 2.5 and 1.5°C respectively).

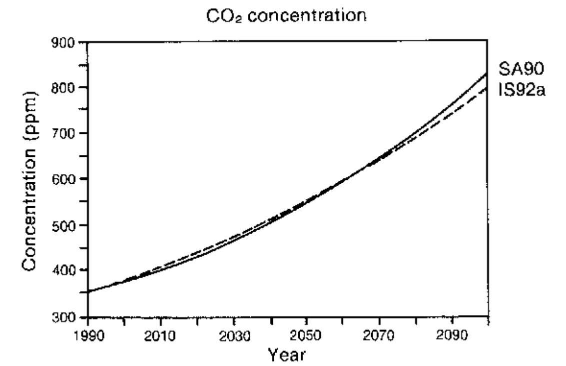

Figure Ax.4: CO_2 concentrations (ppm) derived from IS92a (dashed curve) and SA90 (solid curve).

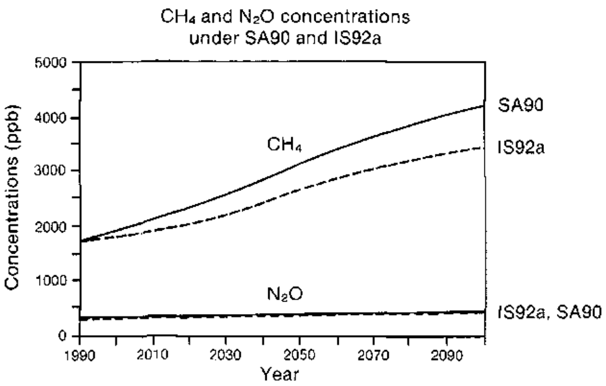

Figure Ax.5: As for Figure Ax.4 but for methane and nitrous oxide. IS92a = dashed curves; SA90 = solid curves.

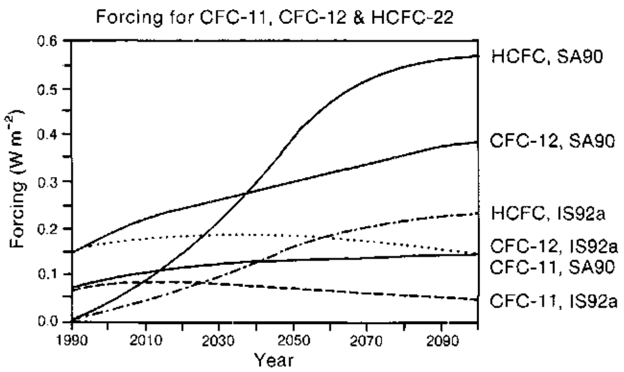

Figure Ax.8: Changes (since pre-industrial times) in radiative forcing (Wm^{-2}) due to the changes in halocarbon concentrations shown in Figure Ax.7. IS92a = dotted and dashed curves; SA90 = solid curves.

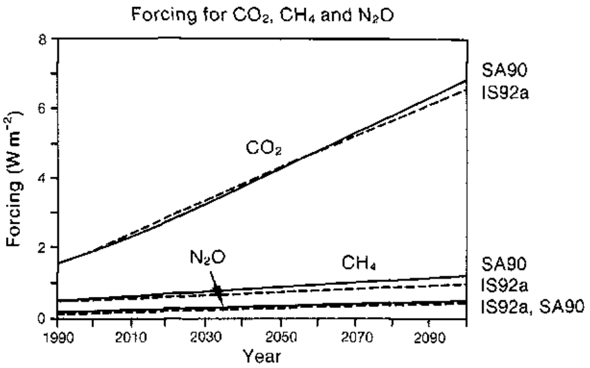

Figure Ax.6: Changes (since pre-industrial times) in radiative forcing (Wm^{-2}) due to increases in carbon dioxide, methane and nitrous oxide. IS92a = dashed curves; SA90 = solid curves.

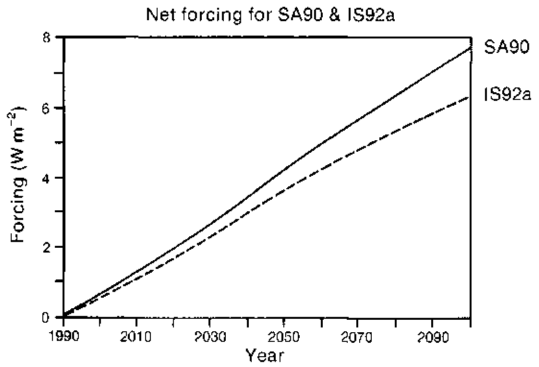

Figure Ax.9: Changes (post-1990) in net radiative forcing under SA90 and IS92a (all gases). No allowance has been made for changes in ozone concentrations or for increases in sulphate aerosols. IS92a = dashed curve; SA90 = solid curve.

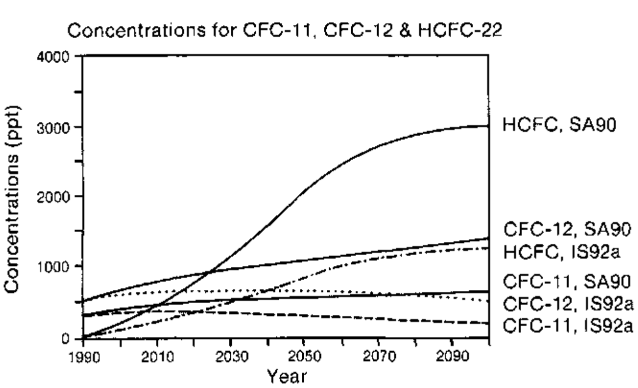

Figure Ax.7: Changes in concentrations (ppt) of HCFC-22, CFC-11 and CFC-12. IS92a = dotted and dashed lines; SA90 = solid curves.

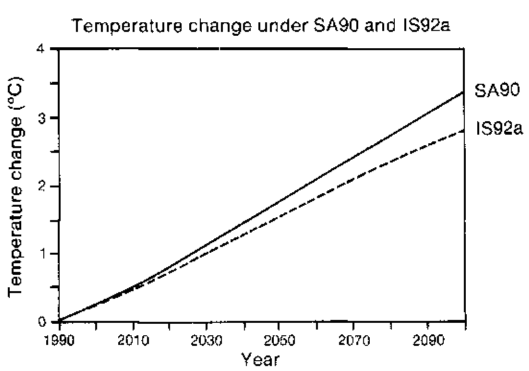

Figure Ax.10: As Figure Ax.9 but showing changes of mean global temperature after 1990 assuming a "Best-estimate" climate sensitivity of 2.5°C. IS92a = dashed curve; SA90 = solid curve.