Simulations of climatic change based on the Mark 2 CSIRO coupled global climatic model using the SRES scenarios with sulphate aerosols

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Abstract

The IPCC Special Report on Emission Scenarios (SRES) data set provides four basic greenhouse gas emission profiles, A1, A2, B1 and B2, which embrace a wide range of possible future atmospheric CO_2, CH_4, N_2O and other gas concentrations. As such they permit potential future climatic changes to be assessed depending on future anthropogenic emissions.

These four SRES scenarios, together with their derived sulphate aerosol burdens, have been used in simulations conducted with the Mark 2 CSIRO coupled global climatic model. These simulations cover the period 1990 to 2100 AD.

Results are presented for a wide range of climatic variables to illustrate the impact of the different scenario members. These highlighted a number of important outcomes.

- There is a considerable degree of mutual compensation between the CO_2−induced warming and the cooling associated with the sulphate aerosols. This could lead to a false interpretation that, because distinct climatic changes associated with a particular scenario may not be apparent over the *next few decades*, the actual CO_2 emission rate is not particularly relevant.
- In the case of climatic change for a *selected region*, differences between scenario members may not be distinct even by 2100 AD.
- However, *global distributions* of climatic change for the last decades of the century indicate fairly systematic effects for, say, surface air temperature, which scale in proportion to the equivalent atmospheric CO_2 concentrations of the individual scenario.
- Patterns of climatic change in such global distributions are robust across the scenario members.
- Interannual variability prevails in the presence of the CO_2−induced climatic change, and is particularly discernible in regional time series of climatic variables.

There is a need to extend the scenarios beyond 2100 AD, assuming the sulphate aerosol burdens continue to decline, in order to delineate more clearly the individual outcomes associated with these scenarios. Scenarios embracing equilibrated or declining atmospheric CO_2 concentrations would be important in this respect.

Introduction

This report evaluates the climatic response of the Mark 2 CSIRO coupled global climatic model to the four principal SRES emission scenarios (A1, A2, B1 and B2). These scenarios specify the atmospheric CO_2 concentrations out to 2100 AD, while the derived aerosol concentrations for these scenarios are also included in the simulations. The scenarios had a common starting date of 1960 and diverged into their individual SRES cases in 1990.

The SRES scenarios represent a range of possible anthropogenically−induced changes to atmospheric composition, and thus permit some assessment to be made concerning the likely climatic outcomes depending on policy decisions that may influence the burning of fossil fuels. Certainly, sustained differences in projected climatic changes, evident in global distributions, were realised by the model towards the end of the simulations, indicating that these scenarios do represent distinct outcomes for consideration by policymakers. As such the scenarios represent a useful advance on the previous, commonly used, cases of the 1% compounding annual increase and the IS92a scenario.

Of course, additional scenarios need to be explored to cover other possibilities. These include situations where atmospheric CO_2 stabilises or decreases at some future date, and ensembles of simulations for a given scenario to allow for chaotic influences on regional climate to be assessed. Some simulations along these lines have been conducted by CSIRO and overseas research centres.

In the body of this report some selected examples of the various SRES simulations are compared and contrasted. What is presented is a very limited sample of the results to illustrate some mainstream climatic changes, no attempt has been made to provide a comprehensive analysis. The latter will be undertaken in an article to be submitted for publication in an international journal.

Model description

The Mark 2 CSIRO coupled global climatic model has atmospheric, oceanic, biospheric and sea−ice components (Gordon and O'Farrell, 1997). The atmospheric model has nine vertical levels and an R21 horizontal resolution (5.625° zonal and 3.25° meridional, providing 3584 gridboxes where physical processes are computed). It includes diurnal and seasonal variability, a mass flux scheme for convection, semi−Lagrangian water vapour transport, gravity wave drag and a cloud parameterisation based on relative humidity. The radiation scheme uses only water vapour, ozone and carbon dioxide to compute radiative temperature tendencies, hence the expected growth of all anthropogenic−influenced gases (CO_4, CH_4, N_2O, fluorocarbons) is represented by an equivalent CO_2 concentration in these simulations. The radiative forcing values needed for the equivalent CO_2 calculations were taken from Myhre *et al*. (1998). The radiative impact of the sulphate aerosols is represented by a simple modification to the surface albedo of the model, with aerosol optical properties following Kiehl and Briegleb (1993).

Land−surface processes are represented by a soil−canopy model with three soil types and 12 plant types, which are temporally invariant. The sea−ice component included ice thermodynamics, while the ice dynamics was controlled by both wind stress and oceanic currents.

The oceanic model was based on the GFDL code, with temperature and salinity gridboxes coincident with those of the atmospheric model physics grid. Potential temperature and salinity were mixed along isopycnal coordinates. Vertical diffusion was a function of the local static stability, except between the three uppermost oceanic levels where a larger diffusivity was used to represent winding forcing of the mixed layer. Convective mixing was parameterised with a large vertical diffusivity (10^6 cm^2 s^{-1}) in regions of static instability. Horizontal diffusivity was replaced by eddy−induced advection according to the Gent−McWilliams scheme. The oceanic model had 21 vertical levels and realistic bottom topography.

Initial conditions and simulation details

The equivalent CO_2 concentrations and aerosol masses specified for the four SRES scenarios are plotted in Fig.1 and Fig.2 respectively. The aerosol values for the A1, A2 and B2 scenarios were supplied by NCAR, and were generated in climatic model runs that included sulphate chemistry code. The aerosol values for the B1 scenario were scaled from the B2 values by the ratio of their respective global mean SO_2 emissions. Observed greenhouse gas concentrations for 1870 to 1990 were used, while the sulphate concentrations were based on NCAR−supplied 1985 concentrations, scaled by annual emissions relative to that year. The initial CO_2 concentration was set to 330 ppm, as used in the model control calculations. The equivalent CO_2 was scaled relative to this so that the evolution of the radiative forcing is correct.

The three−dimensional ozone concentrations used in the GCM, again supplied by NCAR, were reconstructed values from 1870 to 1990 and incorporated expected changes in ozone up to 2100 associated with impacts expected following the implementation of the Montreal protocol.

The CSIRO coupled model was initiated from an existing simulation that had been spun up for 150 years using the 1870 ozone concentrations and an equivalent CO_2 concentration of 330 ppm. The model was then integrated forward to 1990 using the CO_2 and aerosol values shown in Fig.1 and Fig.2. This simulation was performed under the previous ACACIA contract. From 1990 to 2100 four simulations were generated corresponding to the specified equivalent CO_2 and aerosol values unique to the individual SRES scenarios shown in Fig. 1 and Fig.2.

An important point to note from Fig.1 and Fig.2 is that, while the CO_2 concentrations increase inexorably over the duration of the simulations, the aerosol values peak around 2025 to 2030 in the case of the A1 and A2 scenarios, and all four scenarios reveal decreasing aerosol values towards the end of the century. This results in an interplay between the CO_2−induced greenhouse warming and the cooling impact of the aerosols, which is neither constant in time or between the SRES scenarios. Thus a simple scaling of climatic outcomes between these scenarios based on their CO_2 concentration profiles is not immediately apparent.