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Using a Climate Scenario Generator for Vulnerability & Adaptation Assessments

MAGICC and SCENGEN

volume 2

NATIONAL COMMUNICATIONS SUPPORT PROGRAMME

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USING A CLIMATE SCENARIO GENERATOR FOR VULNERABILITY AND ADAPTATION ASSESSMENTS: MAGICC AND SCENGEN VERSION 2.4 WORKBOOK

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FOREWORD

This Workbook on generating climate scenarios using MAGICC and SCENGEN does not provide all the answers, but it does give countries the tools they need to develop their own solutions. It is aimed at non-Annex I Parties that are engaged in the process of preparing vulnerability and adaptation (V&A) assessments for their national communications under the United Nations Framework Convention on Climate Change (UNFCCC). The use of this step-by-step Workbook will facilitate the construction of national and regional climate scenarios, but more importantly, it discusses many of the scientific and technical issues that are commonly encountered by national teams on climate change during their work. For example, it suggests that incremental scenarios can be used to test the sensitivity of impact models and systems to climate change. Sensitivity analysis, when undertaken in conjunction with impacts and adaptation analyses, and with climate change generators, provides a powerful methodology for V & A assessments.

This Workbook was initiated by a request from countries to the National Communications Support Programme at one of its regional workshops on V & A assessments in Central America (Mexico City, Mexico, 8-10 September 1999). Technical assistance for constructing climate scenarios was further requested at other regional workshops. In response, the Support Programme commissioned this Workbook, consistent with its mandate to assist non-Annex I Parties to prepare their national communications.

The Support Programme does not, however, prescribe or endorse the use of any single approach in V&A assessments. It merely presents this climate scenario generator (i.e., MAGICC/SCENGEN) as one of the most commonly requested generators, whilst recognising that other options are available. Nonetheless, MAGICC/SCENGEN has several advantages. It provides a user-friendly, low-cost and flexible tool for generating regional and national climate scenarios for anywhere in the world. It draws closely upon the science and data sets assessed by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. It uses extensive observed climate data sets and outputs of General Circulation Models to allow users to explore and quantify different aspects of uncertainty with regard to future climate. Several countries already have extensive experience in its use. Further details of the software are provided in a companion Technical Manual (Wigley *et al.*, 2000; see also Raper *et al.*, 1996), which is being published to coincide with the release of this Workbook.

MAGICC/SCENGEN has a number of limitations. It relies on pattern-scaling methods to describe a wide range of scenarios; the additive downscaling technique is simple; observed climate data are restricted to 0.5º latitude/longitude resolution and in this version are only available for four large regions at this resolution; and inter-annual climate variability is not fully considered. Some of these limitations will be addressed in the near future. A new version of MAGICC will be prepared in 2001 to reproduce the results in the IPCC Third Assessment Report. It will also include the full set of the approved SRES emissions scenarios. Two major enhancements to SCENGEN are also envisaged. First will be the inclusion of an observed mean monthly climate data set at 0.5º resolution for all global land areas, and second will be the ability of SCENGEN to describe future changes in inter-annual climate variability. The results of these on-going developments should be available in about two to three years time.

Meanwhile, in conjunction with the Support Programme, consideration is also being given to the development of an integrated training package for constructing climate scenarios. This training package might be built around the use of climate scenario generators, but would also aim to encompass wider issues in climate scenario design, including the role of regional climate models, weather generators and other downscaling techniques. Preliminary discussions are underway with the IPCC Task Group on Climate Scenarios for Impact Assessment and others.

Over time, it is intended that all of the above initiatives would result in an improved version of this Workbook and software, if requested by countries. As a part of this series, other workbooks are planned to address the construction of socio-economic scenarios and adaptation to climate change. Language versions of these various workbooks will also be available shortly.

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May 2000

The National Communications Support Programme does not endorse the use of any single model or method for national-scale assessments of climate change. It encourages the use of a range of models and methods appropriate to national circumstances.

1: INTRODUCTION

1.1: Using Scenarios in Vulnerability and Adaptation Assessments

Climate is changing. So too are some of our assumptions about our ability to cope with climate variability. These changes have fuelled concerns about how well we could cope in the future with accelerated climate change, concerns that are reflected in the UN Framework Convention on Climate Change (UNFCCC; http://www.unfccc.de), drafted at the Earth Summit in Rio in June 1992. These concerns have also driven the subsequent process of moving towards a protocol aimed at beginning to control greenhouse gas emissions – the Kyoto Protocol. Also fuelling this process has been the series of very warm years experienced globally during the 1990s, with 1998 being the single warmest year recorded using instrumental data (Figure 1.1), and the unusual behaviour of the El Niño/Southern Oscillation (ENSO) during the 1980s and 1990s (Trenberth and Hoar, 1996).

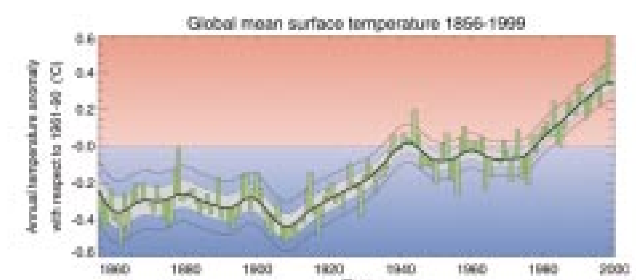

Figure 1.1: *Global-mean temperature series, 1856-1999. Anomalies from the 1961-90 average.*

The UNFCCC requires non-Annex I Parties to prepare initial national communications that may include vulnerability and adaptation (V&A) assessments of climate change, and to submit these to the UNFCCC Secretariat. A number of such assessments have already been submitted, but a much larger number are currently underway with technical support from the National Communications Support Programme (NCSP) office at UNDP in New York (http://www.undp.org/cc). These assessments explore and, where possible, quantify the vulnerability of various systems and sectors to climate variability and to climate change. They also identify a reasonable range and character of anticipated future climate changes that may affect a country or region. Small magnitudes of climate change occurring slowly are easier to adapt to than large magnitudes of climate change occurring rapidly. It is also important to identify critical thresholds of regional climate change beyond which whole systems or sectors may collapse or become unable to function effectively. Such analyses are necessary to contribute to the debate about what constitutes dangerous anthropogenic interference with the climate system (Article 2 of the UNFCCC; http://www.unfccc.de/resource/conv/index.html).

For all these reasons, national and regional V&A assessments not only need comprehensive information (see Annex D) about present and recent climate variability as it affects different countries and regions, but they also need robust descriptions of future regional climates at the finest possible spatial and temporal scales. How can such descriptions be achieved?

Climate prediction is still a relatively young science and is beset by a number of difficulties. One of these difficulties relates to having to look several decades into the future to make estimates about the possible rate and level at which the world community will continue to emit greenhouse gases. Many of the driving factors of such emissions are highly uncertain and cannot be predicted with any confidence. Another difficulty relates to the design of appropriate climate models, ones that incorporate all the important feedbacks that exist in the coupled atmosphere-ocean-biosphere-society system. Some of these feedbacks are still only crudely represented in the most sophisticated of climate models - General Circulation Models (GCMs). A related difficulty concerns the problem of modelling a system that displays elements of unpredictability; this requires multiple GCM simulations in order to separate human "signal" from natural "noise". One consequence of the above problems is that uncertainties about future climate remain large; for example, for some regions we are not even sure whether total precipitation will increase or decrease due to global warming.

For these reasons a range of climate scenarios needs to be designed and applied in climate change impact studies. This range needs to be carefully constructed to capture an "appropriate" part of the uncertainty associated with climate change. What is "appropriate" depends on the application and on the assumptions of the scenario designers. Use of a single climate scenario in a V&A assessment fails to convey to policy advisors the uncertainties inherent in future climate prediction.

Few country study teams have the capacity, resources or time to undertake dedicated experiments using global or regional climate models for the production of national or regional climate scenarios. Such models take many months to install, test and commission, and it may take many further months, if not years, to design, conduct and diagnose a suitable set of experiments. They also demand considerable computing capacity and technical expertise. For these reasons, simple climate scenario generators (CSGs) are useful if: 1) they can emulate the behaviour of more complex models; 2) they can rapidly and efficiently explore climate prediction uncertainties; and 3) they can easily be used in many different regions. A number of such CSGs have been developed and successfully applied in recent years (see Annex C for some examples).

The combination of the simple climate model called MAGICC and the climate scenario database called SCENGEN forms one such scenario generator. Demonstrating the use of this particular generator for V & A assessments is the purpose of this Workbook. MAGICC /SCENGEN has already been widely tested in over 20 national V&A studies. The Workbook is designed to assist in the preparation of non-Annex I national communications and has been commissioned by the NCSP of the UNDP/GEF. While it should be noted that the NCSP does not endorse the use of any one model, this Workbook was prepared in response to a large number of requests from non-Annex I Parties. Earlier drafts of the Workbook were extensively reviewed by experts from both Annex I and non-Annex I countries.

This publication has been timed to accompany the recent release of Version 2.4 of the MAGICC/SCENGEN software, which is provided as a CD-ROM with this Workbook (inside back cover). Version 2.4 of MAGICC reproduces the results at global scale that were reported in the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report and that are summarised in Kattenberg *et al.* (1996) and Warrick *et al.* (1996). In addition to the IS92 emissions scenarios used in the Second Assessment Report, MAGICC 2.4 also includes the four draft SRES (Special Report on Emissions Scenarios) Marker emissions scenarios that form a subset of the 40 SRES emissions scenarios that will be widely used in the IPCC Third Assessment Report. Version 2.4 of SCENGEN contains results from a large number of General Circulation Model experiments, including both the set currently posted on the IPCC Data Distribution Centre (DDC) (http://ipcc-ddc.cru.uea.ac.uk/index.html) and others that are being used in the IPCC Third Assessment Report. The software therefore allows users to generate global and regional mean climate change scenarios that in a general sense are comparable to those being used and reported by the IPCC. Further background information about climate change scenarios, about General Circulation Models, and about their use in impacts assessments is now available in the Guidance Material prepared by the IPCC Task Group on Scenarios for Climate Impact Assessment (TGCIA) and recently made available through the IPCC DDC (http://ipcc-ddc.cru.uea.ac.uk/cru_data/support /guidelines.html).

This Guidance Material can be accessed for a more complete briefing about the development and application of climate scenarios for impact assessments. For example, this guidance strongly recommends that country teams also use incremental (sometimes called arbitrary) scenarios to test the sensitivity of their impact models and systems to climate change.

A Technical Manual to accompany Version 2.4 of MAGICC/SCENGEN is also available as a companion document to this one (Wigley *et al.*, 2000). This Technical Manual has been written by the designers of the software and copies can be obtained as indicated in Annex B.

1.2: MAGICC – Calculating Global Climate Change

MAGICC - Model for the Assessment of Greenhouse-gas Induced Climate Change – is a set of linked simple models that, collectively, fall in the genre of a Simple Climate Model as defined by Harvey *et al.* (1997). MAGICC is not a GCM, but it uses a series of reduced-form models to emulate the behaviour of fully three-dimensional, dynamic GCMs. MAGICC calculates the annual-mean global surface air temperature and global-mean sea-level implications of emissions scenarios for greenhouse gases and sulphur dioxide (Raper *et al.*, 1996). Users are able to choose which emissions scenarios to use, or to define their own, and also to alter a number of model parameters to explore uncertainty. The model has been widely used by the IPCC in their various assessments (see Annex B for a history of MAGICC). MAGICC can be used on its own with no loss of function, but has also been designed to be used in conjunction with SCENGEN.

1.3: SCENGEN – Portraying Regional Climate Change

SCENGEN – a global and regional SCENario GENerator – is not a climate model; rather it is a simple database that contains the results of a large number of GCM experiments, as well as an observed global and four regional climate data sets. These various data fields are manipulated by SCENGEN, using the information about the rate and magnitude of global warming supplied by MAGICC and directed by the user's choice of important climate scenario characteristics.

SCENGEN has been developed over a number of years (see Annex B for a history of SCENGEN) to operate in conjunction with MAGICC, but can be used on its own in a more limited function. SCENGEN has not been officially used by the IPCC, but nearly all of the data sets used by SCENGEN – GCMs and observations – have been used or assessed in different IPCC assessments including the Third Assessment Report due to be published in 2001.

2: KEY FUNCTIONS OF THE SOFTWARE

MAGICC/SCENGEN[1] converts scenarios of greenhouse gas and sulphur dioxide emissions into estimates of global-mean surface air temperature and sea-level change and then into descriptions of future changes in average regional climate (Figure 2.1). The user can intervene in the design of the global or regional climate change scenarios in the following ways:

- Selecting and/or specifying the greenhouse gas and sulphur dioxide emissions scenarios;
- Defining the values for a limited set of climate model parameters in MAGICC concerned with uncertainties in the carbon cycle, in the magnitude of sulphate aerosol forcing, and in the overall sensitivity of the global climate system to changes introduced by humans;
- Selecting which set of GCM results are to be used;
- Specifying for which future period(s) during the twenty-first century the results are to be displayed.

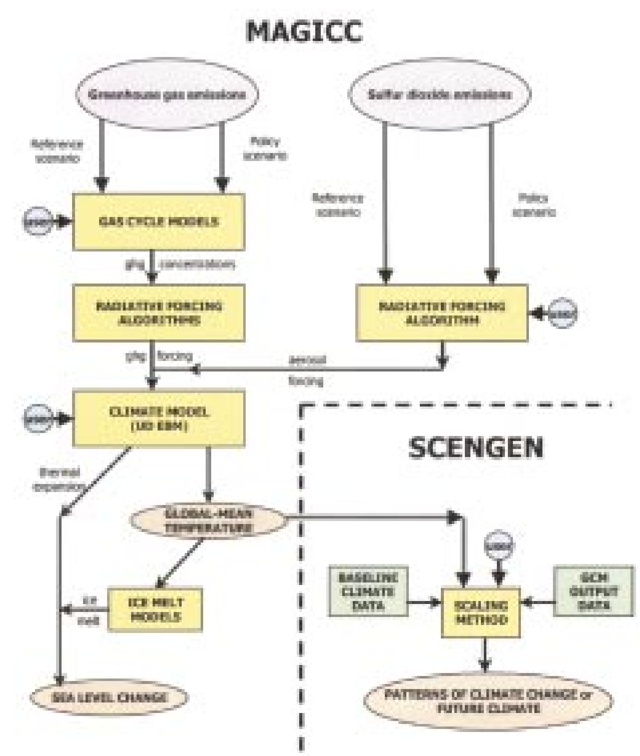

Figure 2.1: *A schematic diagram showing the main inputs, operations and outputs of the MAGICC/SCENGEN software.*

This section sets out the key functions of the software, while Section 3 illustrates the main uncertainties in climate change scenarios that can be explored using MAGICC and SCENGEN. Section 4 shows how a national climate change scenario might be constructed, while Section 5 illustrates some other applications of the software. Section 6 discusses some of the limitations of MAGICC/SCENGEN and suggests further developments that may be needed.

2.1: MAGICC - Model for the Assessment of Greenhouse-gas Induced Climate Change

MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single software package. This software allows the user to determine changes in atmospheric carbon dioxide (CO_2) concentration, global-mean surface air temperature and sea-level between the years 1990 and 2100, resulting from anthropogenic emissions of CO_2, methane (CH_4), nitrous oxide (N_2O), the halocarbons (e.g. HCFCs, HFCs, PFCs) and sulphur dioxide (SO_2). The years 1990[2] and 2100 are the default start and end years used by the software, but they can be varied in MAGICC. The main aims of MAGICC are:

- to compare, within any individual model run, the global climate implications of two different emissions scenarios. One of these two scenarios MAGICC terms a "reference" scenario and one a "policy" scenario, although this terminology allows for *any* two emissions scenarios to be evaluated, whether or not they derive from the imposition of climate policies.
- to determine the sensitivity of the results of the different emissions scenarios to changes in the model parameters. Basic uncertainty ranges are calculated by default, but in addition, the results of a given emissions scenario for a user-specified set of model parameters may be compared with those generated by the default set of parameter values.

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[1] Installation instructions for the software can be found on the inside back cover. [2] See Box 2.2 (p.11) for a discussion of why 1990 is the default start year.

2.1.1: Running MAGICC

On starting MAGICC the main menu will be displayed, as shown in Figure 2.2.

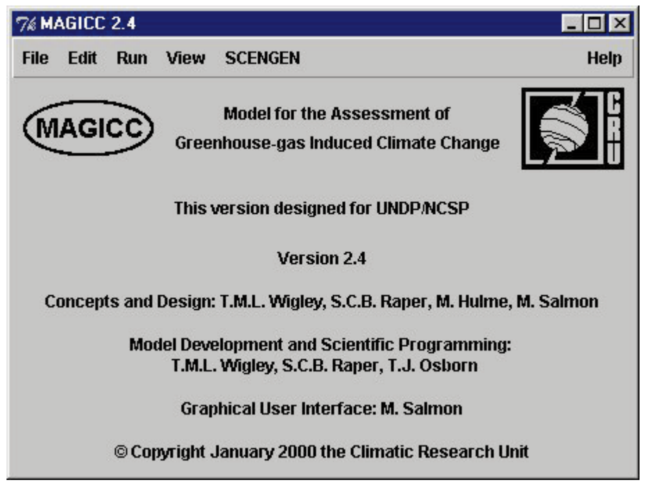


Figure 2.2: *The MAGICC title page and main menu. The main menu choices can be seen at the top of this display, i.e.,* ***File, Edit, Run, View, SCENGEN*** *and* ***Help.***

Operation of MAGICC can be separated into a number of distinct steps:

- Selection of the emissions scenarios (choose **Edit** menu)
- Changing the model parameters (choose **Edit** menu)
- Selecting the output years (choose **Edit** menu)
- Running the model (choose **Run** menu)
- Viewing the results, either as report files or as graphs (choose **View** menu)
- Printing the results (choose **View** menu)

MAGICC is supported by a comprehensive on-line help system. If you need help at any time, click on the **Help** button, either on the main menu or on the sub-menu you are viewing.

2.1.2: Selection of the Emissions Scenarios

The first step in MAGICC is to make use of one of the nineteen pre-defined emissions scenarios or to construct a user-defined emissions scenario. Click on the **Edit** heading on the MAGICC main menu and then select **Emissions scenarios** from the pull-down menu. The **Emissions scenarios** sub-menu illustrated in Figure 2.3 will appear.

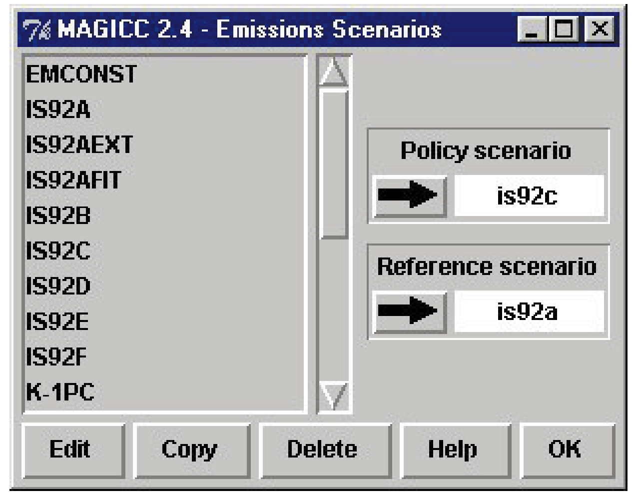


Figure 2.3: *The emissions scenarios sub-menu.*

The IS92a and IS92c emissions scenarios are pre-defined as the default "reference" and default "policy" emissions scenarios, respectively[3]. If you wish to select a different pre-defined emissions scenario to represent one of your two chosen scenarios, then simply click on the relevant scenario and then on either the **Reference** or **Policy** arrow to load it into MAGICC. Alternatively, you can create your own emissions scenarios by changing the fossil fuel CO_2, deforestation CO_2, CH_4, N_2O and SO_2 emissions. To do this, select one of the pre-defined scenarios and then click on the **Copy** button. You will be asked for a short filename (maximum 8 characters) for the new scenario, as well as for a longer description. The name you have chosen for your scenario will subsequently appear in the list of pre-defined scenarios. To edit the new scenario (or one of the existing scenarios, e.g., to update the emissions information), select the scenario from the list and then click on the **Edit** button at the bottom of this sub-menu. Either creating a new scenario, or editing an existing one, will result in the appearance of a window similar to the one shown in Figure 2.4. Box 2.1 discusses the emissions numbers that can then be changed.

IMPORTANT NOTE: To create a new emissions scenario, remember to **Copy** an existing scenario into a new emissions file before editing the numbers; otherwise you will overwrite the original emissions scenario. You may find it useful to make back-ups of the MAGICC emissions files to prevent accidental deletion. You will find these listed as *.gas files in your Windows MAGICC directory.

[3] IS92a has been widely used by IPCC and other organisations as a reference emissions scenario and the IS92c scenario has the lowest emissions in the IS92 set of scenarios. Section 5 compares these IS92 scenarios with the draft set of SRES scenarios prepared by IPCC for the Third Assessment Report.

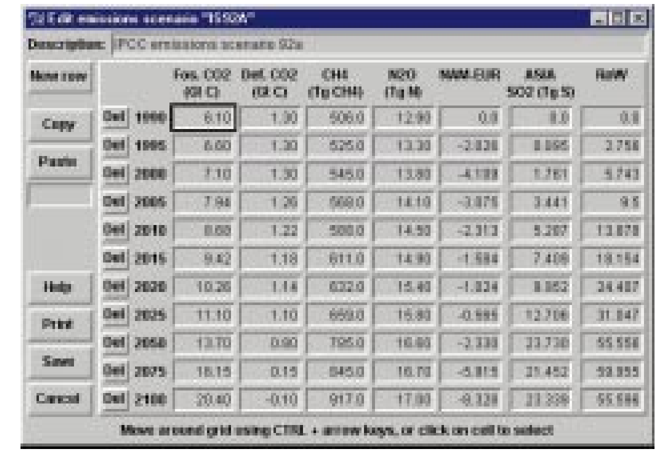


Figure 2.4: *The edit emissions profile window, which allows the user to create a completely new emissions scenario, or to edit the emissions for one of the pre-defined scenarios.*

2.1.3: Changing the MAGICC Model Parameters

There are a number of model parameters in MAGICC that may be changed by the user. These relate to the carbon cycle model, to current aerosol forcing and to the climate sensitivity. If you wish to change any of the default model parameter values then click on the **Edit** heading on the MAGICC main menu and then select **Model parameters** from the pull-down menu. Figure 2.5 illustrates the sub-menu that will appear. Changing any of the model parameters will create what MAGICC calls a "user model"; the "default model" using the default parameters is nevertheless always used by MAGICC as well as any user-defined model. For more details about these parameters, see the Technical Manual (Wigley *et al*., 2000).

Box 2.1: What emissions numbers can I change?

- The 1990 emissions values in the MAGICC emissions files should not be altered.
- CO_2 emissions are divided into those from fossil energy sources ('Fos.') and those from net land use change ('Def.').
- You should note that for CO_2, emissions are shown as total estimated anthropogenic emissions, while for CH_4 and N_2O emissions are total, i.e., natural plus anthropogenic. For SO_2, however, emissions are shown relative to 1990, i.e., 1990 should always be set to zero.
- Negative emissions can be entered, but in the case of fossil CO_2 this implies human sources have converted to net human sinks - for example, negative values for 'Def. CO_2' imply human land use changes act as a carbon sink rather than source. For SO_2, negative emissions imply levels below 1990 emissions and are legitimate.
- Emissions for SO_2 should be entered as three regional components – Europe and North America (NAM-EUR), Asia (ASIA), and the Rest of the World (RoW). This regional disaggregation only becomes relevant if sulphate aerosol-induced climate change patterns are to be viewed in SCENGEN. The results displayed by MAGICC are insensitive to how global SO_2 emissions are partitioned between these three regions. See Figure 2.10 (p.16) for the definition of the three regions.
- MAGICC also responds to emissions of halocarbons, but these profiles are hard-wired into the model and cannot be changed by the user. This is because the production of most (but not all) greenhouse-related halocarbons are now effectively controlled by the Montreal Protocol and its adjustments and amendments, and therefore the atmospheric concentrations of these gases can be reasonably well predicted. MAGICC uses assumptions about halocarbon emissions published in the IPCC Second Assessment Report.

You can move around the matrix shown in Figure 2.4 using the Control and arrow keys on your keyboard to amend the values as necessary. Once you have made your changes, click on the **Save** button and you will be returned to the emissions profiles sub-menu. If you wish to use your newly created or amended emissions scenario, then remember to enter it into either the "reference" or "policy" scenario box. You can delete any of the profiles that you have created simply by selecting the profile and then clicking on the **Delete** button. Once you have made your profile selections to represent the "reference" and "policy" emissions scenarios then click on the **OK** button and you will be returned to the main MAGICC menu.

Carbon cycle parameter

In the carbon cycle model the D_n80s (1980s-mean net deforestation) value can be changed by the user. This is the 1980s-mean value of net land-use change CO_2 emissions and gives an indication of the assumed CO_2 fertilisation effect. The default value used here corresponds to the IPCC Second Assessment Report mid-range value (i.e., 1.1 Gigatonnes carbon [GtC] per year; Schimel *et al*., 1995). MAGICC runs the carbon cycle model three times using this default value and also the IPCC-defined range in the D_n80s value, namely 0.4 and 1.8 GtC yr^{-1}. These values determine the high and low ends of the range in the CO_2 concentration graphs (seen using the **View** option on the main menu). However, only the mid-range (and user) value is used in subsequent climate model calculations. Also see pp.22 for an interpretation of this parameter.

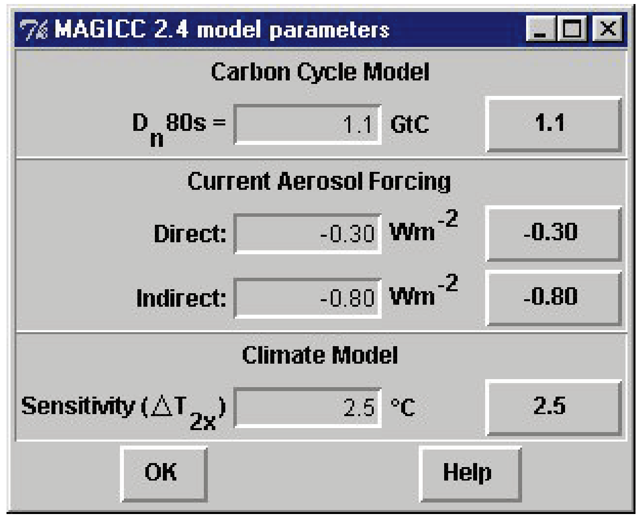


Figure 2.5: *The model parameters sub-menu displaying the default model parameters used by MAGICC. The user can change any of these values by simply clicking in the appropriate window and changing the selected value as desired. The raised buttons on the right-hand side of this menu indicate the default values used by MAGICC. If you make changes to the parameter values and then decide that you wish to change back to the original default values, simply click on this button and the default value will reappear in the window.*

Aerosol forcing parameters

There are three components to the aerosol forcing used by MAGICC - direct, indirect and biospheric (see Box 3.1, p.23). These forcing values are highly uncertain. In all cases the default values are as used in the IPCC Second Assessment Report (Kattenberg *et al.*, 1996). The values of the direct and indirect aerosol forcing can be changed by the user to reflect different estimates of the strength of the aerosol forcing, but positive values imply a positive radiative forcing and should not be used. Click on the **Help** button for more information about these values. See also p.23 for an assessment of the uncertainty attached to these parameters.

Climate model parameters

In the climate model, the user can change the climate model sensitivity (ΔT_{2x}). The climate sensitivity defines the equilibrium response of the global-mean surface air temperature to a doubling of atmospheric CO_2 concentration. The IPCC range[4] for the climate sensitivity remains 1.5°C to 4.5°C, with a mid-range estimate of 2.5°C. MAGICC runs the climate model three times using each of these climate sensitivity values in turn, thus determining the low and high ends of the range of the global temperature projections displayed in the Temperature graphs (seen using the **View** option on the main menu). Once you are satisfied with your choice of model parameters, click on the **OK** button.

REMEMBER: You do not need to change any model parameters unless you so wish. MAGICC will always run with the default settings. If you *have* changed any model parameter settings, however, MAGICC will also run with these settings as a "user model".

2.1.4: Changing the Output Parameters

The final task is to select the output parameters. These allow you to define the nature of the output calculated and displayed by MAGICC. Once again, click on the **Edit** heading on the MAGICC main menu and then on **Output years** on the pull-down menu which appears. The sub-menu illustrated in Figure 2.6 will appear.

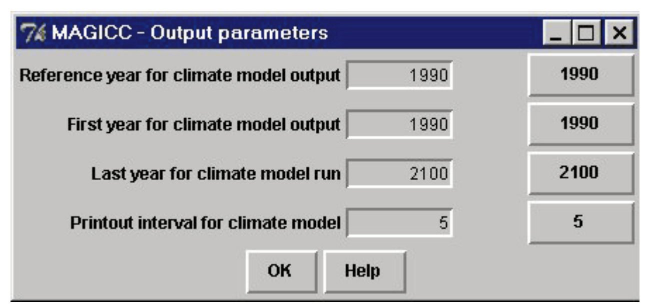


Figure 2.6: *The output parameters sub-menu.*

The **Reference year for climate model output** determines which year is assumed to be the baseline year against which future changes in global-mean temperature and sea-level are calculated. The default year is 1990, corresponding to current IPCC convention. See Box 2.2 (p.11) for a discussion on choice of reference year.

The **First year for climate model output** determines the first year for which the diagnostic information from MAGICC is written to the report files that can be viewed from the MAGICC main menu. The default year is 1990. The **Last year for climate model run** informs MAGICC when to cease calculations and when to cease reporting. The default year is 2100, although the user can enter a later (up to 2500) or earlier value. MAGICC will only calculate changes,

[4] The Third Assessment Report of the IPCC due to be published in 2001 will re-evaluate this range.

Box 2.2: Which reference year should I use in MAGICC?

The default reference year in MAGICC is 1990. This follows the IPCC convention adopted in the First (1990), Second (1996), and Third (2001) Assessment Reports. Other reference years can, however, be chosen. For example, to view changes in climate with respect to the pre-industrial era, the year 1765 could be chosen. This is the initialisation year for MAGICC. Alternatively, the reference period 1961-90 may be preferred since many observed climate normals and gridded climate data sets describe "present" climate as the average of 1961-90. In this case, 1976 should be chosen as the reference "year" for MAGICC since this is the approximate mid-point of the period 1961-90. Whatever reference year is selected, it is important that you document your choice in reports or analyses that use MAGICC results.

Your choice of reference year in MAGICC does not affect your choice of reference year in SCENGEN (cf. Box 2.5, p.17).

however, for periods that are consistent with the emissions gas files - if the gas files end in 2100, then changing the **Last year for climate model run** to, for example, 2200 will have no effect. The **Printout interval for climate model** determines the interval at which the diagnostic information from MAGICC is written to the report files. The default value is 5 years.

Once these selections have been made, click on **OK** at the bottom of this sub-menu and you will be returned to the main menu.

REMEMBER: You will find climate change results in the published literature sometimes shown as changes in climate and impact relative to year 1990 and sometimes relative to other base periods, such as 1961-90. The modelled difference in climate change between difference reference periods can amount to as much as 0.3°C of global warming and 6cm of global sea-level rise in the case of 1990 versus 1961-90. Pay careful attention to how you report and document your results.

2.1.5: Running MAGICC

Having selected your emissions scenarios and made any changes you wish to the **Model Parameters** and **Output Years,** you are now ready to run MAGICC. Click on the **Run** heading on the main MAGICC menu and then on **Run model** on the pull-down menu which appears. Depending on the speed of your computer, MAGICC will take between 7 and 60 seconds to complete its calculations.

2.1.6: Viewing the Results

When MAGICC has finished running, you will be able to view the effects of your selected emissions scenarios and model parameters on greenhouse gas atmospheric concentrations, radiative forcing and global-mean temperature and sea level. Click on **View** on the main menu. You can view graphs of emissions, concentrations, radiative forcing and global-mean temperature and sea level, or, alternatively, you can inspect the report files for the default and user cases for either the "reference" or "policy" scenarios.

On selecting **Emissions** from the **View** menu, a window similar to that in Figure 2.7 will appear. The emissions scenarios that you have selected to be your "reference" and "policy" scenarios are indicated in the graph title. You can view the individual gases (CO_2, CH_4, N_2O and SO_2) by clicking on the appropriately-labelled diamond in the top left-hand corner of the plotting area[5]. On selecting SO_2, you can see that the three regional profiles - for North America and Europe, Asia and the Rest of the World - are shown in addition to the global total. Once you have finished viewing the **Gas emissions** click on the **OK** button and you will be returned to the main menu.

By selecting **Concentrations** from the **View** menu, you can view the atmospheric concentrations of CO_2, CH_4 and N_2O resulting from your emissions scenarios. In addition to the "best"[6] estimate concentrations for CO_2 and CH_4, a range in future concentrations may also be viewed for the "reference" and "policy" scenarios by activating the appropriate buttons on the left-hand side of the plotting area. The CO_2 concentration range corresponds to the high and low D_n80s values, as defined by the IPCC, being used in the carbon-cycle model, while the CH_4 concentration range is a function of uncertainties in methane model parameters. For N_2O concentrations only a "best" estimate is available. There are also three pre-defined time periods (1765-1990, 1990-2100 and 1765-2100) which you can view by clicking on the appropriate button. You can also view a different time period by editing the values in the year selection boxes; you may wish, for example, to view results beyond 2100 - but only if you allowed MAGICC to run beyond this date (see Section 2.1.4; p.10). Once you have finished viewing the **Gas concentrations** click on the **OK** button and you will be returned to the main menu.

[5] For CH_4 and N_2O, the total (anthropogenic plus natural) emissions are displayed, irrespective of which component was input in your gas files. If the input has a 1990 budget imbalance, MAGICC corrects this and outputs the balanced values. SO_2 emissions shown are as input, except that appropriate regional baseline (1990) values are added to give absolute anthropogenic-only emissions.

[6] Where "best" is used in MAGICC and this Workbook, it is generally used to imply the mid-range value out of a range of possible values. It should *not* be interpreted as being prescriptive.

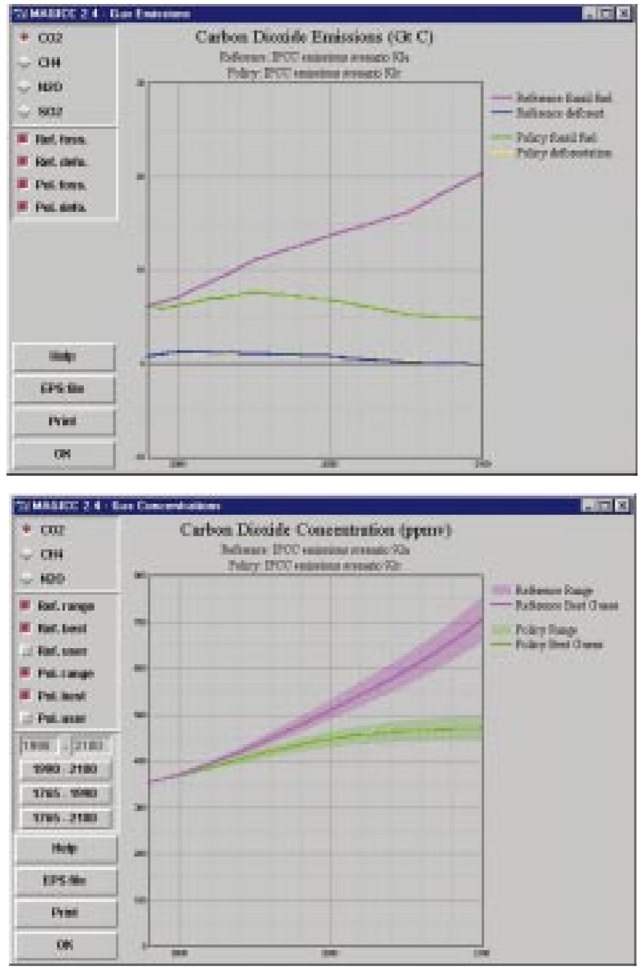


Figure 2.7: The initial window that appears on selecting ***Emissions*** *(top) or* ***Concentrations*** *(bottom) from the View menu. The other greenhouse gas emissions (and SO_2) or concentrations can be viewed by clicking on the appropriate button in the top left-hand corner of these windows.*

Radiative forcing graphs selected from the **View** menu enable the user to view on-screen the calculated radiative forcing (in Wm^{-2}), either gas-by-gas or as a scenario total. Here, there are four possible curves for each gas corresponding to the "default reference", "default policy", "user reference" and "user policy" scenarios. The default and user curves will only differ if a "user model" was selected (see Figure 2.8). Once you have finished viewing the **Radiative forcing** click on the **OK** button and you will be returned to the main MAGICC menu.

REMEMBER: Aerosol forcing will be negative if SO_2 emissions in your selected emissions scenario are positive (i.e., rise above 1990 levels), but positive if SO_2 emissions are negative (i.e., fall below 1990 levels). This means that sulphate aerosol forcing can lead to either global warming or cooling relative to 1990 climate depending on the global SO_2 emissions scenario.

Finally, you can view the changes in global-mean temperature and sea-level by selecting the **Temperature and Sea level** tab from the **View** menu. Switch between **Temperature** and **Sea level** by selecting the appropriate button on the left-hand side of the plotting area (see Figure 2.9 p.14). Once again you can change the years displayed by selecting one of the three pre-defined time periods, or enter your own values by editing those in the year display boxes. Initially only the **Reference best** estimate is displayed, but you can add the **Reference range, Policy best** estimate, **Policy range** and **Reference user** and **Policy user** values by clicking on the appropriate buttons on the left-hand side of the plotting area. If you did not define a user model then there will be no difference between the **Reference best** and the **Reference user** curves or between the **Policy best** and **Policy user** curves. In addition to these eight curves there are also two others - **Reference con. SO_2** and **Policy con. SO_2**. These two curves result from SO_2 emissions remaining constant at 1990 levels with default model parameter values being used (see Box 2.3). Once you have finished viewing the **Temperature and Sea level** graphs click on the **OK** button and you will be returned to the main MAGICC menu.

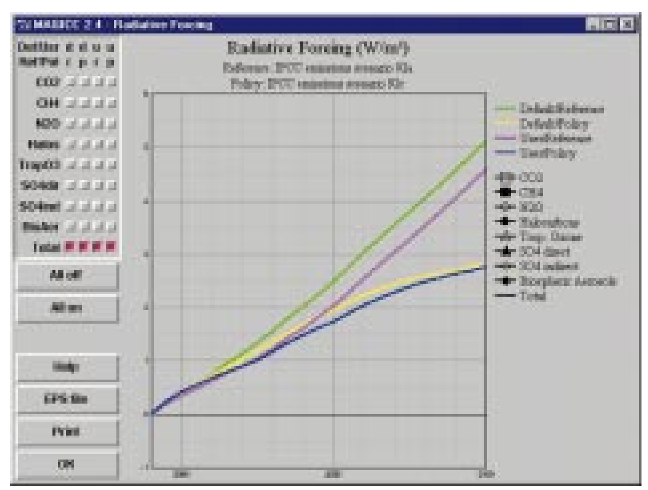


Figure 2.8: Total radiative forcing for the default and user, "reference" and "policy" scenarios. In this case, a user model was created by altering the default model parameters so that the Dn80s value was 1.5 GtC yr^{-1} and the 1990 indirect aerosol forcing was increased to -1.5 Wm^{-2}. "SO4dir" and "SO4ind" refer to the direct and indirect forcing estimates of sulphate aerosols.

REMEMBER: The display 'con. SO2' shows future temperature and sea-level with no additional sulphate aerosol forcing beyond 1990, i.e., sulphate aerosol forcing remains constant at 1990 levels. These curves give an idea of the importance of aerosol forcing in future predictions relative to greenhouse gas forcing.

You are also able to view on-screen the diagnostic output from MAGICC by selecting the **Default Reference, User Reference, Default Policy** or **User Policy** reports from the **View** menu[7]. In each file there are 20 blocks of simulated output (see Annex E p.51 for an example of one block of output). Simulation blocks 9 to 20 can be ignored since they provide information internal to the hand-over of files from MAGICC to SCENGEN. Blocks 1 to 4 relate to different settings of the climate sensitivity. Simulation block 1 sets the sensitivity to 1.5°C, in simulation 2 it is 2.5°C and in simulation 3 it is 4.5°C. For simulation block 4, the climate sensitivity is again set to 2.5°C unless one of the User reports **(Reference or Policy)** is being viewed, in which case the climate sensitivity is set to the user choice, if indeed the user selected a different climate sensitivity value. If not, the value remains at 2.5°C. The second block of four simulations (numbers 5 to 8) in the report files repeats the first block except that the SO_2 emissions are held constant at 1990 levels, i.e., the effects of post-1990 changes in SO_2 emissions from whatever source are excluded from the second block of four simulations.

From these report files it is also possible to extract the calculated values for selected years of radiative forcing, temperature and sea level change and the various gas concentrations (see Annex E, p.51), the latter being listed towards the end of the files. The choices made in the **Output years** sub-menu will govern the frequency at which these values are listed; thus the choice of **Reference year, Printout interval, First year of model output** and **Last year of model run** will affect the diagnostic information found in the report files. Once you have finished viewing the report files click on **OK**.

2.1.7: Printing the Results

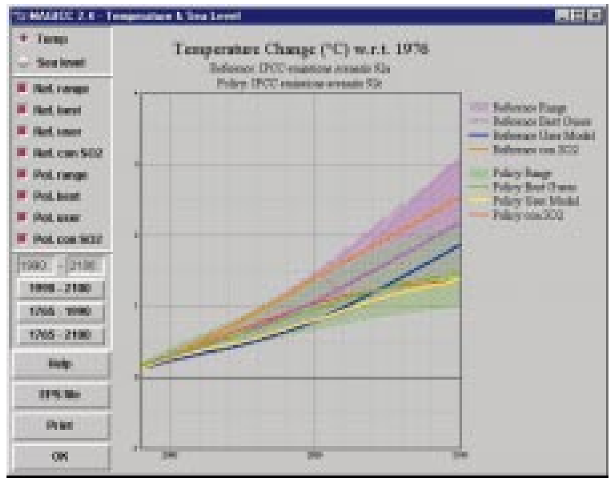
On viewing the graphs, you can generate a direct screen print if you have a Hewlett Packard Postscript printer attached to your PC (select the **Print** button). Alternatively you can save the plot as an encapsulated postscript ("eps") file which you can then import into other software

Box 2.3: How do I interpret these results?

A complete MAGICC analysis will generate 10 projections of global-mean temperature and sea-level (additional runs are also completed for use by SCENGEN when scaling aerosol patterns, but these results are not viewable in MAGICC). Five of these relate to your "reference" scenario and five to your "policy" scenario. Three of these five cases are for default settings of the MAGICC parameters, one each for a climate sensitivity of 1.5ºC, 2.5ºC and 4.5ºC. The remaining two cases for each emissions scenario derive from the "user model" – if indeed one was defined by the user – and from the default model with a 2.5ºC sensitivity, but with no post-1990 sulphate aerosol forcing. In Figure 2.9, p.14, and in the Table below, the "user" model was defined by altering the default model parameters so that the D_n80s value was 1.5GtC yr^{-1} and the indirect aerosol forcing was increased to -1.5Wm^{-2}. The 10 curves shown in Figure 2.9, generate the global temperature increases, with respect to 1961-90 (i.e., MAGICC year 1976), tabulated below:

	2025	2050	2100
IS92a, range	0.4	0.9	0.7
	1.5	1.5	3.1
IS92a, best guess	0.6	1.1	2.2
IS92a, user model	0.5	0.8	1.8
IS92a, con. SO_2	0.8	1.4	2.5
IS92c, range	0.4	0.7	1.0
	0.9	1.4	2.2
IS92c, best guess	0.6	1.0	1.5
IS92c, user model	0.6	0.9	1.6
IS92c, con. SO_2	0.7	1.0	1.4

[7] If you wish to work with these output files outside the MAGICC framework, you will find them in your magicc directory named as "report.dr", "report.ur", "report.dp" and "report.up". But note that they get overwritten each time you run MAGICC.



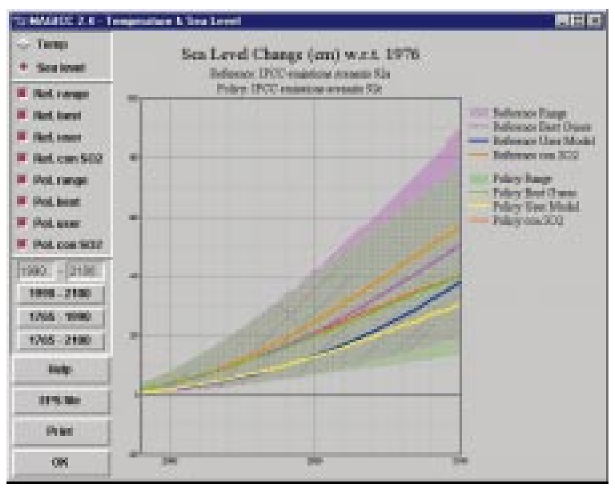


Figure 2.9: *Examples of global-mean temperature (top) and sea-level change (bottom) windows from the View menu. All scenario options are switched on. "Con. SO2" refers to a model run with constant 1990 SO_2 emissions.*

applications or print out as hard copy on a different printer (select the **EPS** button). If you choose the latter, then you will be prompted for a filename into which the encapsulated postscript plot will be written (you should include a filename extension .eps in your filename). It is also possible to capture the full MAGICC screens as a screen-dump which can be imported into Paint Shop Pro. Most of the illustrations in this Workbook were created in this way and so we explain this procedure here[8].

In Paint Shop Pro there are a number of options that allow you to capture the whole screen, the active window or selected areas. First of all you need to set-up the capture process by clicking on the **Capture** tab at the top of the main Paint Shop Pro window and then on **Setup**. Select your desired capture option (e.g., active window) and then the other options concerning how you will initiate the capture process (e.g., click using the right mouse button). Once you have made your choices click on **OK** and you will be returned to the main window. Click on the **Capture** tab again and then on **Start**. The Paint Shop Pro window will automatically minimise so that you are returned to the window that you want to capture. Select the window, or area, and then activate the capture process by clicking on the right mouse button (or however you decided to capture images in the Paint Shop Pro setup section). Return to Paint Shop Pro and you will see the image displayed in the main window. You now need to save the image as a file. Click on the **File** tab and then on **Save As**. Enter the filename and select the format in which you want to save the image from the extensive list. The images displayed in this workbook were saved in "jpeg" format.

The report files are stored as ASCII files in your main MAGICC directory (named: "report.dr", "report.dp", "report.ur" and "report.up") and can be printed out if required. If you have a Hewlett Packard Postscript printer attached directly to your PC then you can use the **Print** button.

IMPORTANT: If you wish to save the report file information for later use, you will need to rename the report files since MAGICC overwrites these files each time the model is run.

You are now ready to use SCENGEN.

2.2: SCENGEN - A Global and Regional Climate Scenario Generator

SCENGEN constructs a range of geographically-explicit climate change scenarios for the world by exploiting the results from MAGICC and a set of GCM experiments, and combining these with observed global and regional climate data sets. SCENGEN contains a set of greenhouse gas-induced patterns of regional climate change obtained from 16 different GCM experiments and also sulphate aerosol-induced patterns of regional climate change obtained from a series of sulphate aerosol experiments performed with the University of Illinois at Urbana-Champagne GCM (UIUC-EQ; Schlesinger *et al*., 2000). Since the GCM experiments report results on different spatial grids, all GCM data were interpolated onto a common 5° latitude/longitude grid before inserting into SCENGEN. Only changes in 30-year average climates are described in SCENGEN Version 2.4; future versions of SCENGEN will also consider changes in interannual climate variability.

[8] There will be a number of other packages that allow this approach; Corel Draw and ArcView maybe two others that can be used. We make no guarantees, except, than for Paint Shop Pro which we have used here.

A geographically-explicit climate change scenario is constructed by selecting a future time interval, by selecting one or more of the greenhouse gas-induced GCM climate change patterns and, optionally, by selecting the regional aerosol patterns. Pattern-scaling methods (see Box 2.4) are employed to create the climate change fields at 5º resolution which can then be added to an observed 1961-90 baseline climate data set to obtain actual climate scenario values for the future time period in question. The global observed climate data set in SCENGEN Version 2.4 exists at a spatial resolution of 5º latitude/longitude (i.e., consistent with the GCM change fields) and for three climate variables - mean temperature, precipitation and cloud cover. For four regions however – Europe, South Asia, USA, southern Africa - Version 2.4 contains observed 1961-90 climate data at 0.5º latitude/longitude resolution, and for a larger set of surface climate variables. Future upgrades to SCENGEN will include a fully global data set at much higher resolution, but for now users are directed to the IPCC Data Distribution Centre (see Annex D, p.50) for access to the *global* 0.5º climate data set.

Click on the **SCENGEN** tab on the main menu in MAGICC and then on **Run SCENGEN**. To view **General information** or **Scientific information** relating to SCENGEN, click on the appropriate button on the title page, otherwise click on **OK** to continue. The main SCENGEN menu, as illustrated in Figure 2.10 (p.16), will appear. Like MAGICC, SCENGEN is supported by a comprehensive on-line Help system - simply click on the **Help** button at the bottom of the main SCENGEN menu to obtain help about any of the features.

Box 2.4: What is the pattern-scaling method for climate scenario construction?

Pattern-scaling methods were introduced into climate scenario construction exercises in order to allow simple and integrated climate models to generate a wide range of climate scenarios without having to re-run a GCM or regional climate model each time a new emissions and/or forcing scenario was created. These methods also allow uncertainties in the climate sensitivity to be easily reflected in climate scenarios. The method was first described by Santer *et al*. (1990), was used in the 1990 IPCC First Assessment Report (Mitchell *et al*., 1990), and was first fully implemented in an integrated assessment model in ESCAPE (Rotmans *et al*., 1994). Many climate scenario and impacts studies and integrated assessment models and climate scenario generators have since used the pattern-scaling method, which is evaluated in the forthcoming IPCC Third Assessment Report.

In simple terms, pattern-scaling works as follows. A global or regional climate change pattern is defined from a GCM climate change experiment, typically as the difference between a future (e.g. 2071-2100) 30-year average climate and the present (e.g. 1961-90) 30-year average climate simulated by the GCM. This pattern is then standardised by dividing by the global-mean warming for the particular model experiment and for the appropriate time-slice (2071-2100 in the example quoted above). The resulting standardised climate change pattern is thus expressed per degree C of global warming.

These standardised GCM patterns are then re-scaled by the desired global warming increment (depending on emissions scenario, climate sensitivity, time-period) derived from a simple climate model such as MAGICC. A similar pattern-scaling method can be used to scale standardised aerosol-induced climate change patterns, although owing to the regional variation in the strength of aerosol forcing these aerosol patterns need to be regional rather than global in scale. Pattern-scaling methods have recently been comprehensively explored by Mitchell *et al*. (1999) and utilised by Schlesinger *et al*. (2000) to explore the implications of the draft SRES emissions scenarios.

Two of the main assumptions of the pattern-scaling method are: 1) that the relative geographical patterns of human-induced change in 30-year average climate, for each forcing component, will remain constant over time; and 2) that the magnitude of the changes is well described by the global-mean temperature change for each forcing component. These assumptions may be a reasonable approximation for many regions and for some climate variables. Pattern-scaling as used in SCENGEN does not allow for non-linear regional climate responses to forcing and does not allow natural decadal variability in climate to be directly represented in the resulting scenarios.

2.2.1: Selecting Global Scenario Options in SCENGEN

The upper portion of the main SCENGEN window consists of the choices available for the construction of the spatial climate change scenario, whilst the lower portion contains a global map with four pre-defined geographical regions (USA, Europe, Southern Africa and South Asia) highlighted in red. These are the regions for which a 0.5º latitude/longitude resolution observed climate data set is included. For regions that fall outside these four pre-defined domains, scenarios can only be displayed as global maps at a 5º latitude/longitude resolution. The SO_2 emissions regions, as used in the MAGICC emissions scenarios, are shown in different colours: region 1 corresponds to North America and Europe (NAM-EUR), region 2 to Asia (ASIA), and region 3 to the Rest of the World (RoW).

Information passed to SCENGEN from MAGICC includes the global-mean temperature changes induced by a) greenhouse gas forcing, and b) each of the three regional SO_2 emissions scenarios in turn. These four global temperature series are provided for each of the two emissions scenarios and for the “default” and “user” models defined in

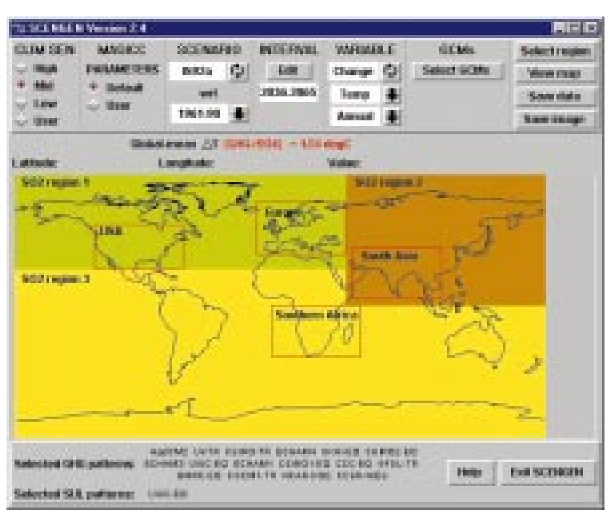


Figure 2.10: *The SCENGEN main menu window.*

MAGICC. In the **Clim Sen** portion of the menu window you can choose between **high** (4.5°C), **mid** (2.5°C), **low** (1.5°C) and **user** values of the climate sensitivity. If you did not specify a **user** value of the climate sensitivity in MAGICC, then clicking on the **user** tab will result in the **mid** climate sensitivity value being used. The effect of changing the climate sensitivity in SCENGEN (and also the MAGICC parameter values and the emissions scenario) is to access a different MAGICC hand-over global temperature file; you will notice this by viewing the global-mean temperature change value (highlighted in red) located immediately above the global map.

You can also specify whether you wish to use the **default** model parameters from MAGICC or, if you made changes to any of the carbon cycle model, current aerosol forcing or climate model parameter values, you can select the user option from the **MAGICC parameters** section. If you did not define a user model in MAGICC then there will be no change in the global-mean temperature change value indicated as you switch between the **default** and **user** options.

REMEMBER: SCENGEN always uses global temperature results obtained from MAGICC. If you wish to assess the effects of a wider range of MAGICC parameters or different emissions scenarios on your regional climate change scenarios, then you must first return to MAGICC and re-run the model with these new settings.

By clicking on the toggle button in the **Scenario** section, you can switch between the two emissions scenarios that you selected as your “reference” and “policy” scenarios in MAGICC. You are also able to select the 30-year reference period from which your changes in climate will be calculated by SCENGEN (Box 2.5). Simply click on the arrow next to the **1961-90** tab and the three available options will be displayed.

The next step is to decide upon the time interval for your scenario of future climate change. The default is the 30-year period centred on 2050 (i.e., 2036-2065). To change this value click on the **Edit** button in the **Interval** section. If you wish to view the 1961-90 observed climate data sets, then click on the **1961-90 baseline** option, otherwise slide the scale until the desired scenario “year” is displayed. Then click on **OK.** The earliest scenario year you can view a climate change field for is “year” 2000 (i.e., average 1986-2015 climate). Your selections of climate sensitivity, MAGICC model parameters, emissions scenario, reference period and scenario interval in the SCENGEN main menu, will determine the global-mean temperature change that is used to scale the spatial patterns of climate change defined by the GCM(s) you select (see below).

VERY IMPORTANT: The global-mean temperature change displayed in red on the SCENGEN screen will by default always be the greenhouse gas only-induced change in temperature. Only if/when you select the GCM aerosol patterns from the **GCMs Select** Menu (see Figure 2.11, p.18) will this value revert to the combined greenhouse gas and aerosol-induced change in global-mean temperature.

Box 2.5: What reference period should I use in SCENGEN?

Maps in SCENGEN are always calculated as depicting 30-year mean climates, or changes in 30-year mean climates. The default reference period in SCENGEN, from which changes are calculated, is 1961-90. This is because the observed baseline climate data sets in SCENGEN represent the 30-year period 1961-90. You can, however, select two other reference periods - “1990”, representing the 30-year period 1976-2005, and “2000”, representing the period 1986-2015. The difference in modelled global warming between these three SCENGEN reference periods is between 0.05°C and 0.3°C depending on the emissions scenario and the choice of climate sensitivity. The “year” 1990 follows IPCC convention adopted in the First (1990), Second (1996), and Third (2001) Assessment Reports. Whatever reference period is selected, it is important that you document this choice in reports or analyses that use SCENGEN results.

Your choice of reference period in SCENGEN can be made independently of your choice of reference year in MAGICC (Box 2.2, p.11.).

2.2.2: Selecting Regional Scenario Options in SCENGEN

The next step is to decide whether you wish to view either the GCM change field for the climate variable in question or the actual climate values. In the former option, the changes in climate relative to your reference period are displayed; in the latter case these climate change fields are added to the appropriate observed 1961-90 climate data. In the **Variable** section click on the toggle button to switch between **Change** fields or **Actual** values and then select the climate variable by clicking on the arrow next to the variable window. For the global fields, only three climate variables are available - mean surface air temperature, precipitation and cloud cover. Click on whichever one of these you wish to view. If you want to view one of the other available regions, then click on the **Select Region** button on the right-hand side of the main SCENGEN window and then select the appropriate region (e.g. USA, Europe, Southern Africa and South Asia) from the pull-down menu which appears[9]. For these four regions a larger number of climate variables are available (e.g. mean surface air temperature, precipitation, cloud cover, maximum temperature, minimum temperature, wind speed, vapour pressure and diurnal temperature range); just click on the desired variable to select. The final requirement in this section is to decide whether you want to view your climate change scenario at monthly, seasonal or annual resolution. Simply click on the arrow next to this selection window and then on the appropriate month or season. In addition to the standard three-month seasons, an additional season - JJAS - has been added since this is important in relation to the Asian monsoon.

You are now ready to select one of the sixteen GCM greenhouse gas only experiments to define the standardised pattern of greenhouse gas-induced climate change and also, optionally, to select the standardised patterns of aerosol-induced cooling/warming derived from sulphate aerosol-forced GCM experiments. On clicking on the **Edit** tab in the **GCMs** section a list of GCMs will appear (see Figure 2.11, p.18). The GCMs are listed in rank order according to one measure of model performance (See Box 2.6, p.19).

To select one (or more) of the GCMs click on the square button on the left-hand side of this menu (see Box 3.2, p.27, for a discussion about which GCMs to choose). If you require more information about each GCM experiment, then click on the **GCM info** button on the right-hand side of this window. If you have selected one of the four regions, rather than the global field, then the climate variable you have selected may not be available for all of the GCMs. If this is the case, then the GCM name is listed in white, rather than in black, and you will not be able to activate this GCM option. If you select GHG change patterns for more than one GCM, then a composite pattern of change will be calculated (see Box 2.7 p.19).

If you decide to include the effects of aerosol-induced regional climate change in your climate change scenario (cf. Box 3.3; p.29), then you will need to select the GCM that contains the aerosol patterns (i.e., UIUC-EQ). Simply click on your choice in the **SO4**[10] **change patterns** section of the **GCM selection** menu and these aerosol induced regional climate change patterns will be combined with your chosen pattern of greenhouse gas induced global warming. Once you have made your selections, click on the OK button and you will be returned to the main SCENGEN menu.

[9] Scenarios for regions outside these four domains can only be displayed in SCENGEN Version 2.4 at a global scale and at 5° latitude/longitude resolution.

[10] Note: SCENGEN uses the nomenclature “SO4” to describe GCM patterns resulting from sulphate aerosol forcing. The precursor gas for such forcing is sulphur dioxide (SO_2)

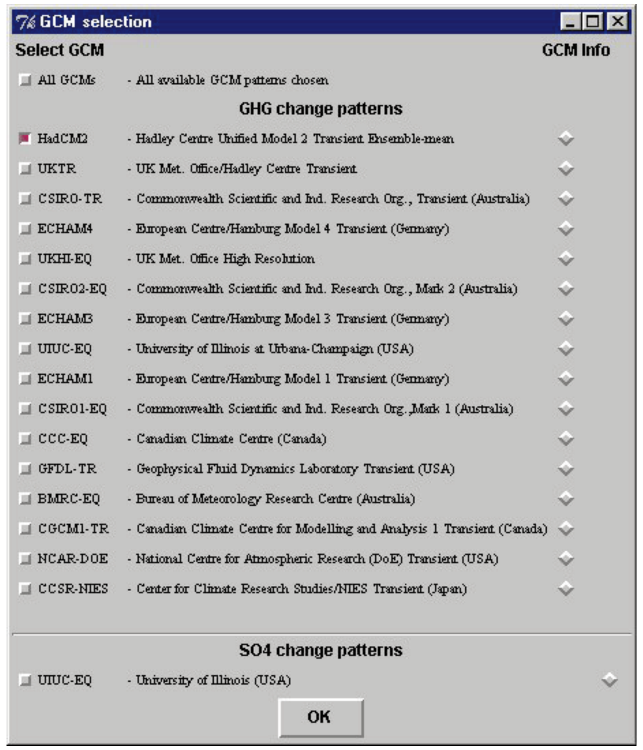


Figure 2.11: *The list of GCMs available in SCENGEN. A GCM, or number of GCMs, is selected by clicking on the square button on the left-hand side of the window. The sulphate aerosol patterns can be selected in the same manner. To view further information about each GCM, click on the diamond-shaped button on the right-hand side of the window*

REMEMBER: The patterns of climate change displayed by SCENGEN will be for greenhouse gas only-induced climate change unless you choose the aerosol patterns GCM (UIUC-EQ) in the SO4 patterns sub-menu of the **Select GCMs** menu.

To view the scenario you have constructed click on the **View map** button on the right-hand side of the main SCENGEN window (see the examples in Figure 2.12). You can easily change any of your previous selections by going back to the appropriate section, making your changes and then clicking **View map** again to redisplay the scenario. Once you have displayed your scenario you can obtain the value for any grid box by moving your mouse over the mapped area. The latitude, longitude and scenario values are displayed just above the mapped area and you can see the values change as you move your mouse around. The full range of the scenario values for the selected geographic domain is also indicated here.

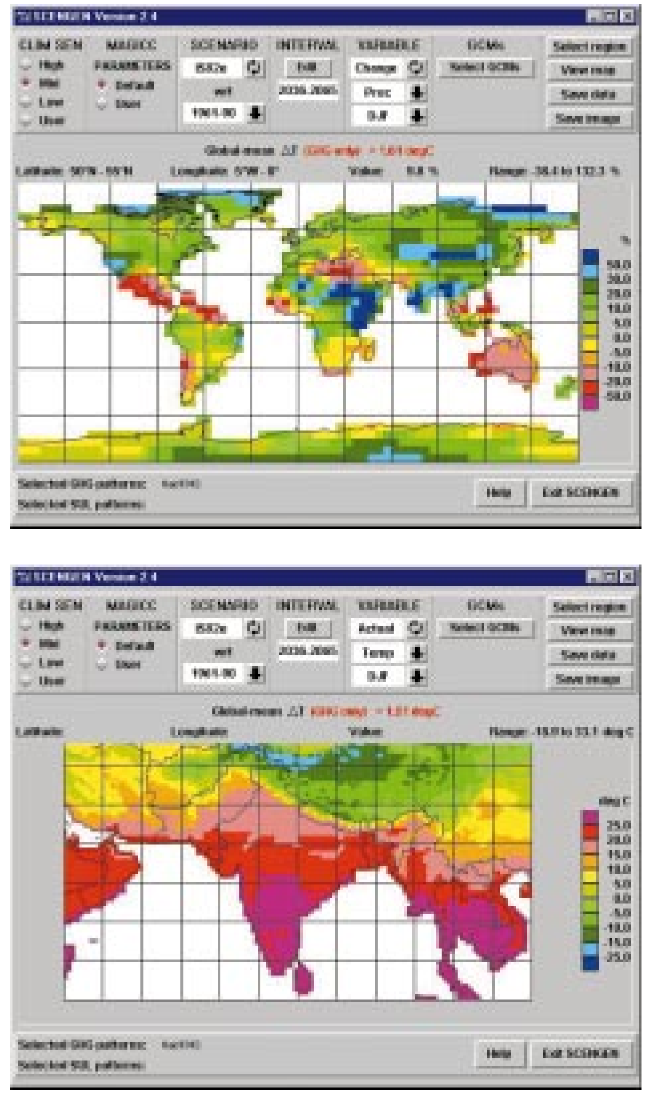


Figure 2.12: *Examples of scenarios constructed using SCENGEN. (Top) Global winter (DJF) precipitation change (%) field for 2050 based on the HadCM2 experiment and the IS92e emissions scenario. (Bottom) Winter (DJF) temperature (°C) in South Asia for 2050, again based on the HadCM2 experiment and the IS92e emissions scenario.*

2.2.3: Saving and Printing SCENGEN Results

Once a climate or climate change scenario has been viewed, you will be able to save the calculated numbers in an ASCII data file. An example is shown in Table 2.1 (p.20). Click on the **Save data** button on the right-hand side of the main SCENGEN menu. You will be prompted for a filename (maximum eight characters) and you can also choose which climate variables you wish to save by clicking on the appropriate variable names in the displayed list. Hence, you can simultaneously save data for all the desired variables without having to view each variable individually in map form. SCENGEN automatically adds a separate default filename extension for each variable. All months, seasons and annual values are saved irrespective of what is being displayed. You can save data for only part of the image by pre-selecting the desired region before clicking on the **Save data** button. Move the mouse to the top left-hand corner of the area you require, click and then drag to the bottom right-hand corner and then release the mouse button. The area selected will be highlighted in red (Figure 2.13, p.20). Now, when you click on the **Save data** button, only the data for the selected area will be saved. These data files will be saved in the scengen/output directory on your PC.

You can also save the image as an "eps" file by clicking on the **Save image** button on the main SCENGEN menu. You will be prompted for an eight-character filename - make sure that you choose a different name for each image you want to save, otherwise the files will be overwritten, although you will be warned if this is the case. You can save the image either with or without captions. If you choose the **with captions** option, then the scenario information (GCM pattern, emissions scenario, time interval, etc.) will be contained in a panel immediately below the map image. However, if you choose the **without captions** option there will be no scenario identification information saved with the image. These *.eps files can be imported into other software packages for printing.

REMEMBER: You also have the option of full screen dumps using Paint Shop Pro (see Section 2.1.7; p.13) which gives you a further range of formatting and printing options for handling SCENGEN maps. The SCENGEN screens used in this Workbook were created this way.

Box 2.6: Assessing GCM performance

There are many ways of assessing the relative performance of GCMs. Their simulation of present climate can be evaluated with respect to surface climate or upper air climate; with respect to patterns of average climate or climate variability; with respect to daily climate or monthly / annual climate; with respect to fidelity to global climate or to regional climate. Most of the GCMs used in SCENGEN have participated in the Atmospheric Model Inter-comparison Project (AMIP; http://www-pcmdi.llnl.gov/amip/amiphome.html) or the Coupled Model Inter-comparison Project (CMIP; http://www-pcmdi.llnl.gov/cmip/cmiphome.html). In SCENGEN we have chosen just one performance criterion - users may wish to make their own assessments, either by following published material (e.g. Gates *et al.*, 1999), or by undertaking evaluation analyses of model performance for their particular region. In the latter case, GCM data for a number of the model experiments used in SCENGEN can be obtained from the IPCC Data Distribution Centre (see Annex C). When comparing GCM estimates of regional climate for the twentieth century against observed data it is important to note that you are comparing simulated climate from a model with low resolution which does not represent local topography, with observed climate data which most likely will reflect local topographic features.

The performance criterion used in SCENGEN is a monthly pattern correlation statistic which describes how well the mean monthly global (land and ocean) precipitation patterns in the control simulation of each GCM experiment reproduce the observed global pattern of mean monthly precipitation (cf. Airey *et al.*, 1996).

Box 2.7: What happens if I choose more than one GCM?

If more than one greenhouse gas change pattern is selected, SCENGEN will calculate and display the average of the selected standardised and re-scaled GCM patterns. This approach of averaging GCMs will produce a composite pattern of climate change. It was first suggested in the context of climate scenarios by Santer *et al.* (1990), has been discussed more recently by Räisänen (1997), and applied by Wigley (1999) and Carter *et al.* (2000) in recent studies. The basis for such model-averaging assumes that the error for different models is random with zero mean. Sampling theory then shows that a model average will yield a better estimate of the greenhouse gas signal than any single model realisation. It should be noted, however, that the fundamental assumption behind this approach is not fully valid, since some of the model-to-model differences are systematic rather than random.

Mean Precipitation (%) Change 2050 Scenario=IS92a wrt - 1961-90
Region = Global delT=1.4degC Clim.sens. = mid Gas Parameters = Default
Unweighted
Selected GHG patterns: HadCM2
Selected SUL patterns:

Lat	Lon	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
47.50	12.50	8.0	6.8	4.3	1.8	-1.3	-5.7	-9.6	-13.2	-5.0	2.0	1.2
47.50	17.50	8.7	8.5	5.2	1.4	-.8	-6.1	-9.9	-12.5	-5.1	1.7	.9
47.50	22.50	4.5	6.5	4.1	1.6	1.6	-5.3	-9.3	-9.4	-6.8	.5	1.4
47.50	27.50	-.3	2.7	2.2	1.7	3.3	-3.9	-7.5	-6.9	-9.9	.0	1.0
47.50	32.50	-3.0	-.6	1.0	1.4	4.8	-2.3	-5.8	-6.2	-12.5	2.0	.8
47.50	37.50	-1.8	-.6	.9	2.3	6.8	-1.5	-5.9	-4.9	-11.3	5.0	3.9
47.50	42.50	1.7	3.0	2.4	5.0	8.5	-.9	-4.3	-.2	-7.8	6.3	10.4
47.50	47.50	5.9	8.5	5.7	9.4	10.7	1.8	1.5	6.7	-3.9	4.8	16.4

Table 2.1: *Example output from SCENGEN. These data show per cent changes in mean precipitation for the period centred on 2050, for the IS92a emissions scenario, with default MAGICC parameters, and the HadCM2 GCM patterns. Note: Output has been truncated in this example.*

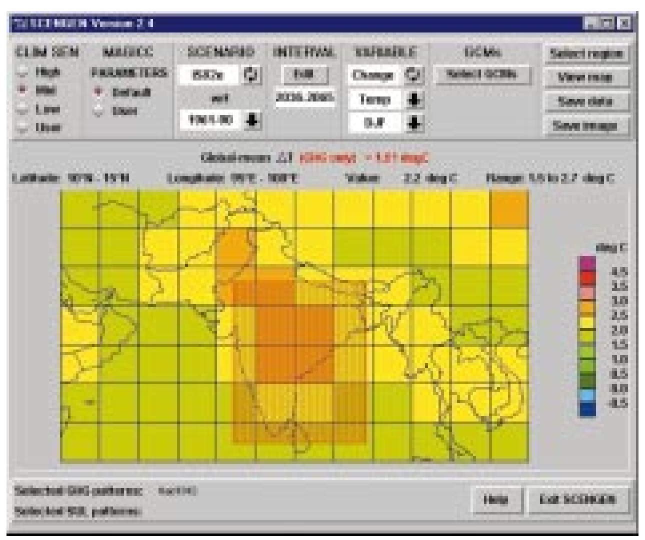


Figure 2.13: *SCENGEN map showing the red box over southern India for defining a user-selected region for saving data to file.*

3: REPRESENTING KEY UNCERTAINTIES IN MAGICC AND SCENGEN

As indicated in the previous section, the user of MAGICC/SCENGEN is able to make a number of decisions concerning the emissions scenarios, MAGICC model parameters and the spatial pattern of climate change used in the construction of the climate change scenarios. These decisions will govern the magnitude, spatial pattern and range of climate changes represented in the resulting scenarios. These options reflect some of the current uncertainties in climate change science and climate prediction. In this section, the uncertainties governing these key MAGICC/SCENGEN options are considered and their effect on the final magnitude and pattern of climate change is examined. Uncertainties in the following components of MAGICC and SCENGEN are considered:

- emissions scenarios
- the carbon cycle
- aerosol radiative forcing
- climate sensitivity
- regional climate change patterns

3.1: Uncertainty in Emissions Scenarios

Future emissions of greenhouse gases into the atmosphere are highly uncertain. These will be a function of changes in population, in economic growth, in technological change and in environmental policy, none of which can be predicted with any certainty. For this reason, it is usual to adopt a range of future emissions scenarios through which to explore possible future changes in climate. Examination of the emissions scenarios sub-menu in MAGICC illustrates the choices immediately available to the user. As indicated in Section 2 (p.7), it is also possible for the user to construct their own emissions scenario, thus further increasing the number of emissions scenarios that can be used in MAGICC, and, ultimately, in SCENGEN.

The emissions scenarios provided in MAGICC (see Table 3.1) include the six scenarios published by the IPCC in 1992 – the IS92 range – and four of the 40 scenarios published in the IPCC Special Report on Emissions Scenarios (IPCC, 2000) – the draft SRES range[11]. In Section 5.1 (p.39), the climate implications of the IS92 and draft SRES emissions scenarios are compared. Each one of these ten scenarios describes an emissions future reflecting different assumptions about population and economic growth and energy technology and efficiency. None of these ten standard IPCC emissions scenarios assumes specific climate policy interventions or the introduction of greenhouse gas emissions targets.

	CO_2 emissions, 2100 (GtC)	SO_2 emissions 2100 (TgS)
IS92a	20.4	146
IS92b	19.2	140
IS92c	4.8	54
IS92d	10.4	64
IS92e	35.9	231
IS92f	26.6	180
SRES A1-B	13.2	31
SRES A2	28.8	64
SRES B1	6.5	32
SRES B2	13.7	51

Table 3.1: *The ten IPCC emissions scenarios included in MAGICC, with global emissions of carbon dioxide and sulphur dioxide by 2100. Note: The SRES emissions refer to the four draft Marker scenarios released by the IPCC in 1998. The SRES A1 scenario shown here is referred to as the A1-B scenario in the final SRES report (IPCC, 2000).*

The two scenarios defining the extreme range of the IS92 greenhouse gas emissions are used here to illustrate the effect of emissions uncertainties on future climate descriptions. Thus IS92c (low) and IS92e (high) are used. IS92e is therefore the “reference” scenario in MAGICC, while IS92c is the “policy” scenario. IS92c assumes the UN medium-low population forecast in which global population by 2100 is less than 6.5 billion. Growth in GNP per capita is assumed to be lower than in IS92a and the availability of oil and gas is also lower, thus resulting in higher prices and in the promotion of nuclear and renewable energy. Deforestation is also expected to be slower because of lower population growth. In the IS92e emissions scenario, the World Bank population forecast is used, in which the total global population approaches 11.5 billion by 2100, and plentiful fossil fuel resources are assumed, although due to an assumed improvement in living standards, environmental surcharges are imposed on their use. Nuclear energy is phased out by 2075 and plentiful fossil fuel resources discourage the additional use of coal-mine methane for energy supply. Deforestation proceeds at the same rate as in IS92a. Halocarbon emissions are the same in both IS92c and IS92e, these being “hard-wired” into MAGICC since such emissions are now largely controlled by the Montreal Protocol[12].

[11] The four draft SRES emissions scenarios were released by the IPCC late in 1998, prior to full IPCC approval, to enable climate modelling and impacts studies to be completed in time for inclusion in the IPCC Third Assessment Report. See also Section 5.1.

[12] Further information about the assumptions behind the IS92 and SRES emissions can be found at the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk/cru_data/examine/emissions/emissions.html).

Figure 3.1 illustrates the CO_2, CH_4 and N_2O emissions associated with the IS92c and IS92e scenarios and Figure 3.2 indicates the associated global-mean temperature and sea - level changes using default MAGICC model parameters. The global warming range is from about 1.5ºC to 2.6ºC and the sea-level rise range from about 40 to 58cm. These differences, therefore, arise solely from different assumed emissions futures and are unrelated to uncertainties in climate science or in climate modelling.

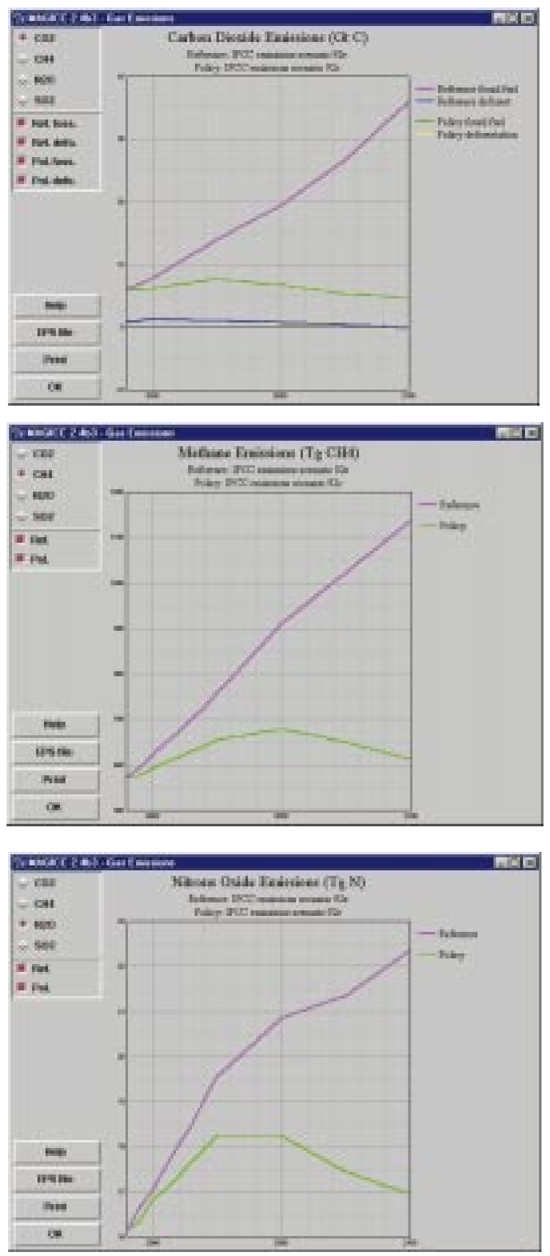


Figure 3.1: *(top) CO_2, (middle) CH_4 and (bottom) N_2O emissions associated with the IS92c and IS92e emissions scenarios.*

REMEMBER: The choice of emissions scenarios is fundamental to the design of climate scenarios. Different emissions scenarios can lead to substantially different rates of climate change in the latter half of the twenty-first century.

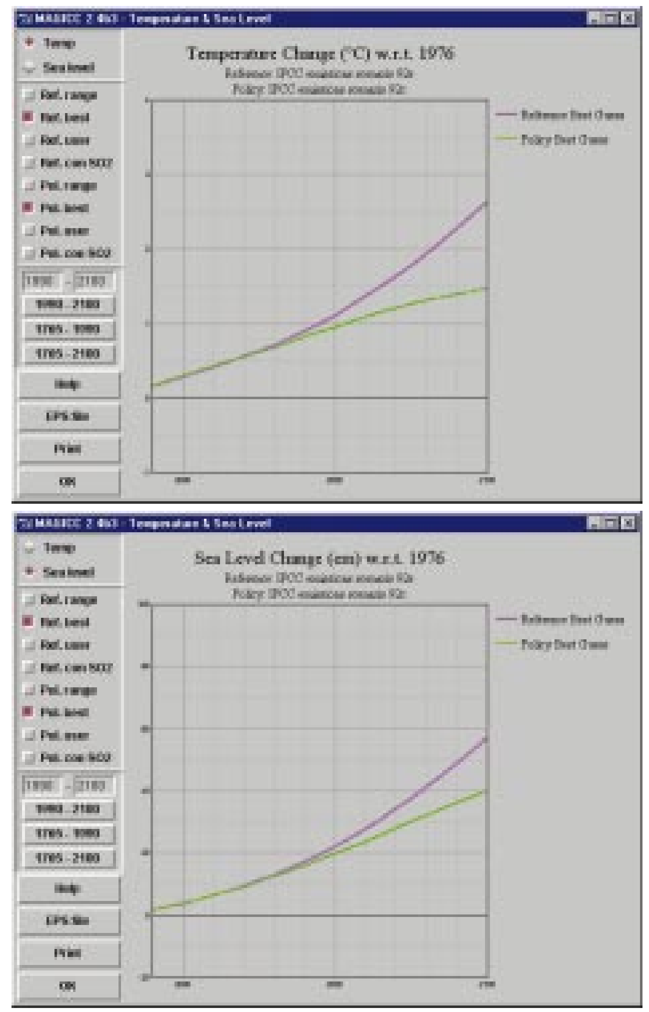


Figure 3.2: *(top) Global-mean temperature change (°C) and (bottom) sea-level rise (cm) associated with the IS92c and IS92e emissions scenarios.*

3.2: Uncertainty in the Carbon Cycle Model

The only parameter in the MAGICC carbon cycle model[13] that may be changed by the user is the net land-use change CO_2 emissions, the D_n80s value. MAGICC automatically runs each time with the low (0.4 GtC yr^{-1}), mid (1.1 GtC yr^{-1}) and high (1.8 GtC yr^{-1}) D_n80s values, this range of values being that used by the IPCC in their Second Assessment Report (Schimel *et al*., 1996). The D_n80s value effectively alters the magnitude of the assumed carbon fertilisation effect in MAGICC, i.e., the biosphere acts as a larger or smaller net carbon 'sink' thus resulting, respectively, in lower or higher atmospheric concentrations of CO_2. The IPCC-defined D_n80s extreme range represents between a 4.5% (D_n80s=0.4) and 30.1% (D_n80s=1.8) increase in net primary biomass productivity for a doubling of CO_2 concentration (from 340 to 680 ppmv). The effect of changing the D_n80s value on atmospheric CO_2 concentration is illustrated in Figure 3.3. The user can explore the role of the assumed carbon fertilisation effect on future atmospheric CO_2 concentration by changing the D_n80s value, although for the purposes of constructing a climate change scenario it is advisable to remain within the IPCC estimates.

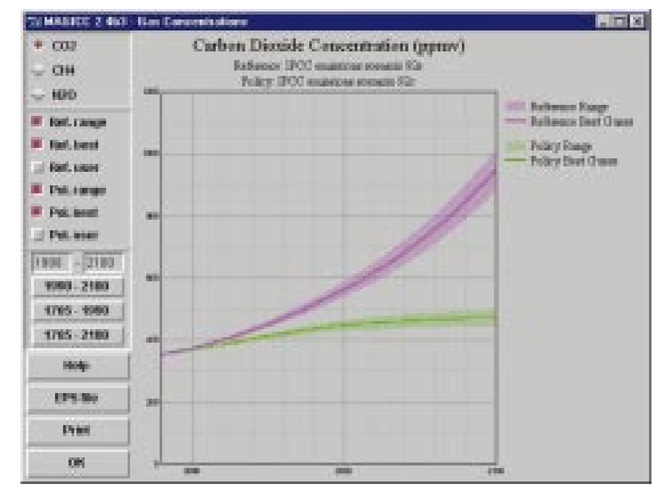


Figure 3.3: *Atmospheric CO_2 concentration (ppmv) associated with the IS92c ("policy") and IS92e ("reference") emissions scenarios. The range in CO_2 concentration is defined by D_n80s values of 0.4 and 1.8 GtC yr^{-1}, whilst the "best guess" values for the two scenarios are derived using a D_n80s value of 1.1 GtC yr^{-1}.*

3.3: Uncertainty in Aerosol Radiative Forcing

In order to estimate future anthropogenic changes in global-mean temperature and sea-level, both past and future radiative forcing changes due to the various greenhouse gases (positive forcing, i.e., a warming effect) and sulphate aerosols (negative forcing, i.e., a cooling effect) should be prescribed. Although the precise relationships between emissions and forcings are uncertain for all greenhouse gases, the most uncertain component of radiative forcing is that due to sulphate aerosols that result from fossil fuel combustion (see Box 3.1).

Figure 3.4[14] illustrates the effect on total forcing in the IS92c and IS92e scenarios of applying the range of IPCC-defined uncertainty in indirect aerosol forcing. It also illustrates the effect of keeping future aerosol forcing constant at 1990 levels. Since SO_2 emissions in the IS92c scenario remain close to their 1990 value, altering the strength of the indirect aerosol effect has little influence on the total scenario forcing which remains around 2.5 Wm^{-2} by 2100. In the IS92e scenario with much higher SO_2 emissions, altering the indirect effect changes the total scenario forcing by 2100 by about 1 Wm^{-2}. The difference in 2100 total forcing between the default case (6.5 Wm^{-2}) and the "constant 1990" aerosols case (8 Wm^{-2}) is substantial. The effects of these radiative forcing differences on global-mean temperature and sea-level are shown in Figure 3.5. For the IS92e scenario, the uncertainty in the indirect aerosol forcing results in a difference of about 0.8ºC and 25cm in global-mean temperature and sea-level, respectively, by 2100. For the IS92c scenario the difference in global-mean temperature by 2100 from this source of uncertainty is negligible because SO_2 emissions remain close to their 1990 levels. The difference in sea-level rise (Figure 3.5) for the IS92c scenario (from 30cm to 45cm by 2100) arises because of the long-term inertial effect of changed historical aerosol forcing on ocean thermal expansion.

3.4: Uncertainty in the Climate Sensitivity

Feedback processes within the climate system, such as those due to water vapour and ice albedo, can either amplify or dampen the system response to anthropogenic forcing. It is deficiencies in our ability to accurately quantify these feedbacks that leads to the large range of uncertainty in the climate sensitivity. MAGICC automatically runs with the

Box 3.1: How large is aerosol forcing?

In MAGICC, the user can explore the effects on future global-mean temperature and sea-level of changing the importance of the aerosol radiative forcing. This forcing is split into three components: the direct clear-sky effect of sulphate aerosols formed from fossil fuel combustion (default value of 1990 forcing -0.3 Wm^{-2}), the indirect forcing (through aerosol-induced changes in cloud albedo, default value –0.8 Wm^{-2}) and the biospheric forcing due to aerosols emitted from biomass burning (fixed at -0.2 Wm^{-2}). These default values are those used in the IPCC Second Assessment Report (Kattenberg *et al*., 1996). Of these three aerosol forcing components, the indirect forcing is the most uncertain. Shine *et al.* (1995) give a range of possible global-mean values of between 0.0 and -1.5 Wm^{-2}, with the default value in MAGICC for this component being set to the approximate mid-value, i.e., -0.8 Wm^{-2}. MAGICC also automatically considers no changes in future aerosol forcing, i.e., SO_2 emissions, and hence aerosol forcing, are kept constant at their 1990 level. This allows the sensitivity of global-mean temperature and sea-level change to aerosol forcing to be determined.

[13] See the MAGICC/SCENGEN Technical Manual (Wigley *et al*., 2000) for more information about the carbon cycle model.

[14] Most of the figures in this Workbook have been obtained by simply capturing the appropriate screens from MAGICC and SCENGEN and using Paint Shop Pro to import them into this document. Where space constraints prevent the reproduction of several screens from MAGICC, as in this case, information derived from the MAGICC report files has been combined into a single graph using Excel.

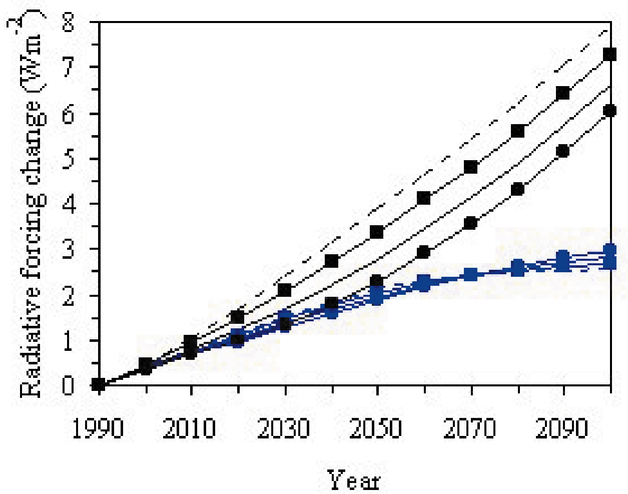


Figure 3.4: Change in total radiative forcing (greenhouse gas plus aerosol; Wm^{-2}) for the IS92c (blue) and IS92e (black) scenarios. The suite of lines are derived by changing the magnitude of the indirect aerosol forcing between the limits defined by the IPCC (Shine et al., 1995) and also by holding the aerosol forcing constant at 1990 levels (dashed line). The effect on the radiative forcing of default indirect forcing (-0.8 Wm^{-2}) is represented by a solid line, of high indirect forcing (-1.5 Wm^{-2}) by filled circles on a solid line and of ignoring indirect aerosol forcing (0.0 Wm^{-2}) by filled squares on a solid line.

three standard IPCC values for the climate sensitivity values (1.5°C, 2.5°C and 4.5°C), but if the user wishes to select a different value, the recommended extreme range is between 0.5°C and 5.5°C. The effect of choosing different climate sensitivity values is examined here initially by considering the global-mean temperature changes for the two emissions scenarios considered in the previous sections - IS92c and IS92e - with the MAGICC model parameters set to default values (see Figure 3.6). For the IS92c scenario, the global-mean temperature change by 2100 may be as little as 1.0°C (low climate sensitivity) or as large as 2.2°C (high climate sensitivity), with the mid-range value being 1.5°C. The corresponding values for the IS92e emissions scenario are 1.8°C, 3.7°C and 2.6°C. The global warming by 2100 from the low emissions scenario with a high climate sensitivity may therefore be higher (2.2ºC) than the global warming from the high emissions scenario with a low climate sensitivity (1.8ºC).

In Section 3.3 (p.23) the effect of changing the indirect aerosol radiative forcing was considered along with the associated changes in global-mean temperature and sea-level. The curves illustrated in Figure 3.5 assumed a climate sensitivity of 2.5°C. However, as well as uncertainty due to poorly known indirect aerosol forcing, there is also the

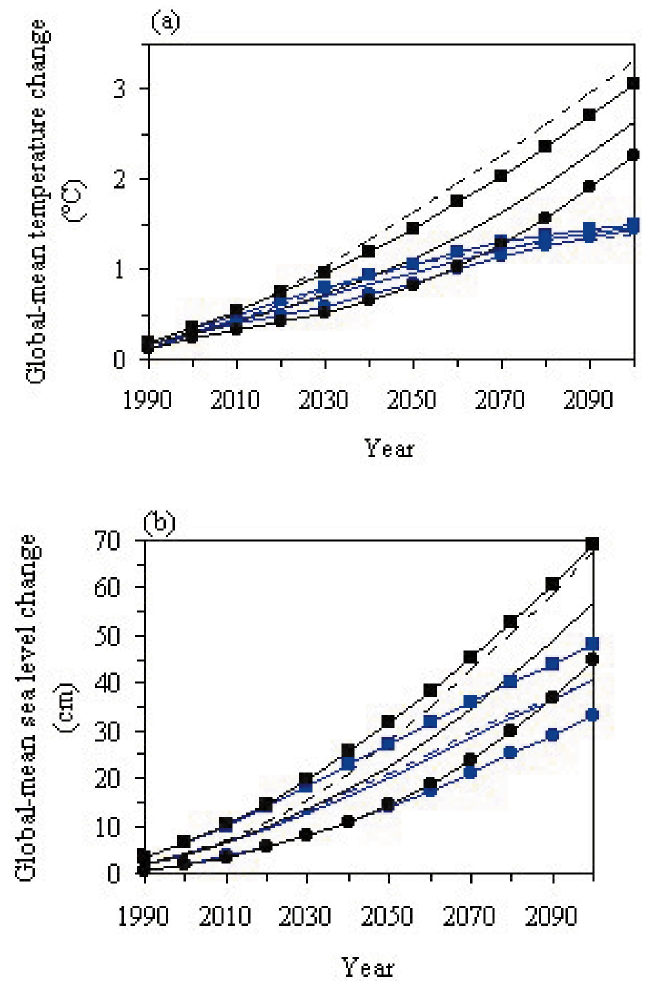


Figure 3.5: Effect of changes in indirect radiative forcing on (top) global-mean temperature change (°C) and (bottom) sea-level change (cm) for the IS92c (blue) and IS92e (black) scenarios, assuming a default climate sensitivity of 2.5°C. The lines correspond to the changes in radiative forcing indicated in Figure 3.4. Changes are with respect to 1961-90.

uncertainty due to climate sensitivity. For each of the curves shown in Figure 3.5, two more can be added to represent the IPCC range in climate sensitivity. Figure 3.7 illustrates this for the IS92e emissions scenario. The range in global-mean temperature change - relative to 1961-90 - for the IS92e emissions scenario associated with the IPCC range in indirect radiative forcing is between 2.3°C and 3.1°C by 2100 (Figure 3.5). If the IPCC range in climate sensitivity is also taken into account, then the range in global-mean temperature change is 1.6°C to 4.4°C by 2100, i.e., a 2°C expansion in the range of 2100 global-mean temperature change (Figure 3.7).

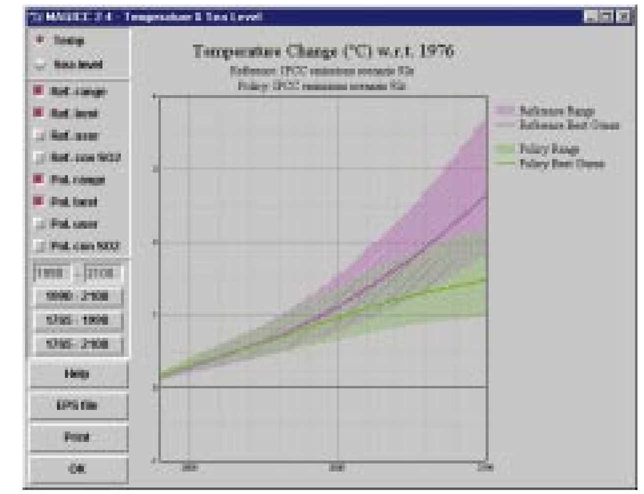


Figure 3.6: Global-mean temperature change (°C), with respect to 1961-90, for the IS92c ("policy") and IS92e ("reference") emissions scenarios. For each emissions scenario the solid line represents a climate sensitivity of 2.5°C, whilst the shaded area represents the IPCC-defined range in climate sensitivity, i.e., 1.5°C to 4.5°C.

3.5: Uncertainties in Regional Climate Change Patterns

The uncertainties described in the previous sections relate to MAGICC, but their effects can be passed onto SCENGEN via the global-mean temperature change. It is this value which is used to scale the standardised patterns of regional climate change in SCENGEN. The main uncertainty in SCENGEN itself relates to the selection of the spatial pattern of climate change. In SCENGEN, the user has access to a number of greenhouse gas related climate change patterns derived from GCM experiments and standardised to a global-mean warming of 1°C, together with a set of standardised regional patterns derived from sulphate aerosol forced GCM experiments. It is possible therefore to create regional climate change scenarios using only greenhouse gas related patterns, or to combine these with the aerosol-induced patterns of change to create an integrated greenhouse gas and sulphate aerosol related climate change scenario. In order to construct scenarios of the spatial patterns of climate change in this manner, the following assumptions are made in SCENGEN (cf. Box 2.4, p.15, for further discussion):

- the greenhouse gas and sulphate aerosol forced patterns of climate change are adequately defined by the GCM experiments from which they are extracted;
- these anthropogenic climate change patterns are manifest linearly in the climate system as a function of global warming (due to greenhouse gases) or regional warming/cooling (due to aerosols) increments;
- the (assumed) distinct greenhouse gas and aerosol forced patterns of change are additive, i.e., the separate patterns can be combined using different weights to create robust and meaningful integrated climate scenarios.

The effects of simply selecting a number of different GCMs to describe the spatial pattern of climate change are first examined. The effects of sulphate aerosols on these regional patterns are then considered.

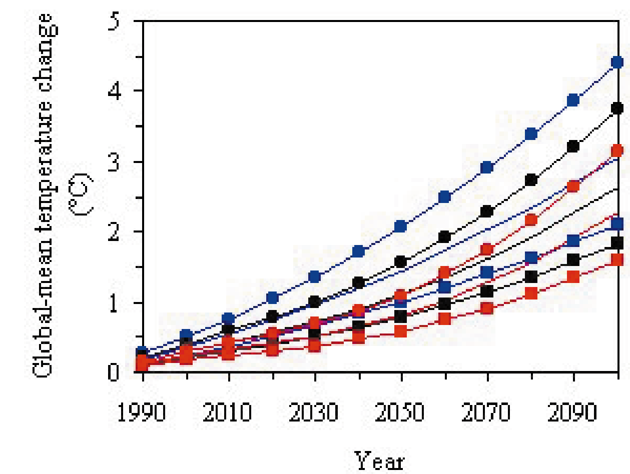


Figure 3.7: The effect on global-mean temperature change (°C) of considering the IPCC uncertainty ranges for indirect radiative forcing and climate sensitivity for the IS92e emissions scenario. The default radiative forcing settings are represented in black, blue indicates where the indirect forcing is ignored (0.0 Wm^{-2}) and red indicates where the indirect forcing is at a maximum (-1.5 Wm^{-2}). Solid lines represent a climate sensitivity of 2.5°C, lines with filled circles a climate sensitivity of 4.5°C and lines with filled squares a climate sensitivity of 1.5°C.

3.5.1: Uncertainties Related to GCM Selection

Figure 3.8 illustrates the spatial patterns of temperature change over South Asia in 2050 for the DJF winter season, derived from the HadCM2 and UIUC-EQ greenhouse gas only experiments[15]. These patterns are scaled according to the global-mean temperature change derived from the IS92e emissions scenario and the default MAGICC model parameters. The greenhouse gas only warming by 2050, with respect to 1961-90, is about 1.6ºC. Figure 3.9 shows the corresponding precipitation changes for the JJAS summer monsoon season. The regional patterns of climate change derived from these two GCM experiments are quite different. The HadCM2 pattern indicates the largest winter warming over the Indian sub-continent (between 2.5ºC and 3.0ºC), whilst a more general north-south pattern is apparent in the UIUC-EQ scenario, with the northern areas warming

[15] These two GCMs are chosen merely for illustrative purposes; other combinations of GCMs could also illustrate the point.

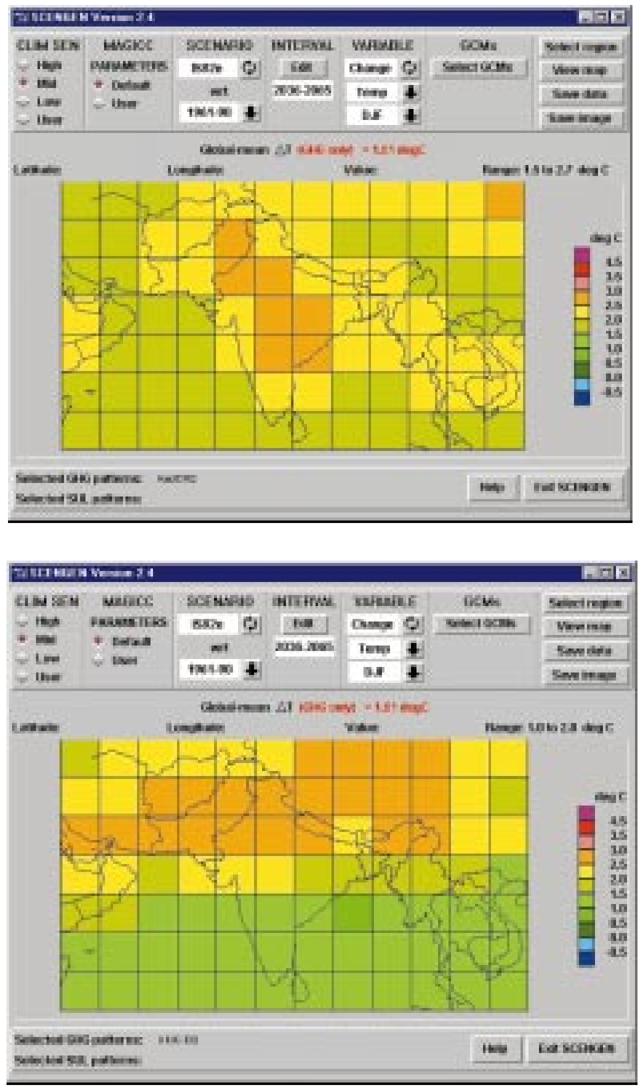


Figure 3.8: *An illustration of uncertainty in the pattern of regional climate change using greenhouse gas only forcing. The change in mean DJF temperature (°C) over South Asia corresponding to the IS92e emissions scenario and default MAGICC model parameters for the "year" 2050: (top) HadCM2; (bottom) UIUC-EQ.*

more than those in the south. The warming is generally greater in the HadCM2 scenario. The difference in the spatial patterns of monsoon precipitation change is even more apparent (Figure 3.9). The changes indicated by the HadCM2 and UIUC-EQ patterns are almost inversely correlated over most of the Indian sub-continent – UIUC-EQ indicates a wetting (precipitation increase) and HadCM2 a drying (precipitation decrease). This is an extreme example and different GCM patterns agree more substantially in their predictions for some other regions and for some seasons, but Figure 3.9 demonstrates how large this source of uncertainty in future climate scenarios may be. Precipitation occurrence and amount in this region is highly dependent on the behaviour of the Asian monsoon and it is widely recognised that some GCMs have difficulty in adequately simulating this regional feature of the climate system. Users interested in undertaking impacts assessments in this region would be advised to select one or more of the GCMs that are able to simulate well the current climate conditions in this region (see Box 3.2 for further discussion about choosing GCMs in scenario construction).

3.5.2: Uncertainties Related to Sulphate Aerosol Patterns

The effect of sulphate aerosols on the patterns and magnitude of temperature and precipitation change in the South Asia region are considered by combining the regional pattern of climate change derived from the UIUC-EQ sulphate aerosol experiments with the greenhouse gas change patterns from HadCM2[16]. The IS92e emissions scenario is again used, with default MAGICC parameters and "year" 2050 displayed. The SO_2 emissions in the IS92e scenario are large over this region (and globally) and their inclusion in the scenario construction reduces the global warming from about 1.6ºC (cf. Figures 3.8 and 3.9) to about 1.1ºC (Figures 3.10 and 3.11, p.28). This again is chosen as an extreme example of the uncertainties introduced by whether or not aerosol effects are included – increases in SO_2 emissions in many of the IS92 emissions scenarios are not so large and most of the new IPCC SRES emissions scenarios actually have reductions in SO_2 emissions compared to 1990 levels (see Section 5.1, p.39). It is now generally thought that the SO_2 emissions scenarios in the IS92 series are unrealistic. Nevertheless, these cases are still useful in assessing sensitivities to sulphate aerosol uncertainties.

The magnitude of mean winter temperature change over the region has generally been reduced as a result of including sulphate aerosol effects (Figure 3.10, p.28). Inclusion of sulphate aerosol effects also leads to changes in the spatial pattern of summer monsoon precipitation change (Figure 3.11, p.28). The areas of precipitation decrease generated by the HadCM2 greenhouse gas only pattern are not so widespread once aerosol effects are included, with parts of the region now seeing small precipitation increases. Box 3.3 (p.29) provides some guidance on whether or not to include aerosol effects in climate scenario construction.

[16] Of course, the aerosol patterns can be combined with any one, or more, GCM greenhouse gas patterns, not just HadCM2.

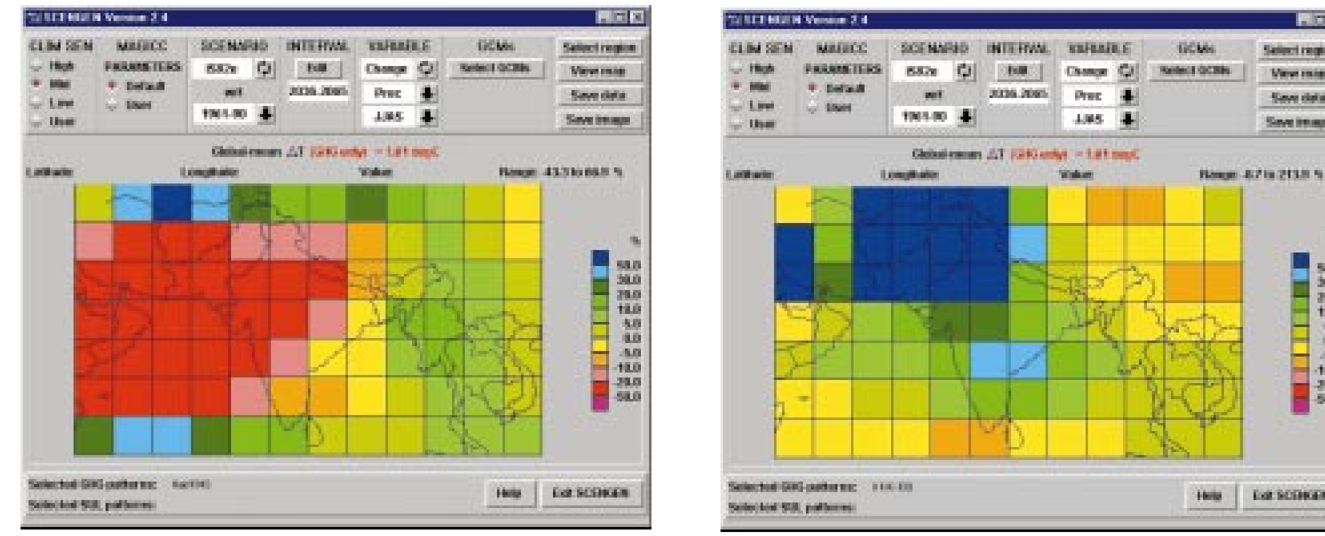


Figure 3.9: *An illustration of uncertainty in the pattern of regional climate change using greenhouse gas only forcing. The percent change in summer monsoon (JJAS) precipitation over South Asia corresponding to the IS92e emissions scenario and default MAGICC model parameters for the "year" 2050: (top) HadCM2; (bottom) UIUC-EQ.*

Box 3.2: Which GCM pattern(s) should I choose?

GCM patterns have been selected in the literature using one or more of the following criteria (Smith and Hulme, 1998): model vintage, model evaluation, model resolution and model representativeness:

- Model vintage is related to the age of the GCM experiment. Recent GCM experiments may be more desirable to use than older ones, since they often will model more recent knowledge about climate system behaviour and response.
- Model evaluation is one of the criteria that has most often been used in GCM selection. The argument is that GCMs that better represent the present climate are more likely to better simulate future climates. See Box 2.6 (p.19) for discussion of the range of evaluation statistics that can be used.
- A model resolution criterion is based on the supposition that models with finer spatial resolution are better able to represent more climate process dynamics than coarser resolution models.
- Model representativeness is used as a selection criterion to reflect a wide range of possible future climates using only two or three GCMs. This approach has been used by Hulme (1996) and Centella *et al.* (1999) to represent uncertainties related to future regional precipitation patterns in the climate change scenarios.

Alternatively, you can use a combination of criteria. In this way, Centella *et al.* (1999) justified their GCM selection using model representativeness and model evaluation as the main criteria, but they also used model resolution and model vintage to reinforce their choices. Finally, it is also possible to define a composite GCM pattern (see Box 2.7, p.19), to equally weight all (or a number of) model outcomes, and to present the results in terms of an average GCM output and range (Wigley, 1999; Carter *et al.*, 2000). Whatever criteria are used, your report should clearly show the basis for GCM(s) selection.

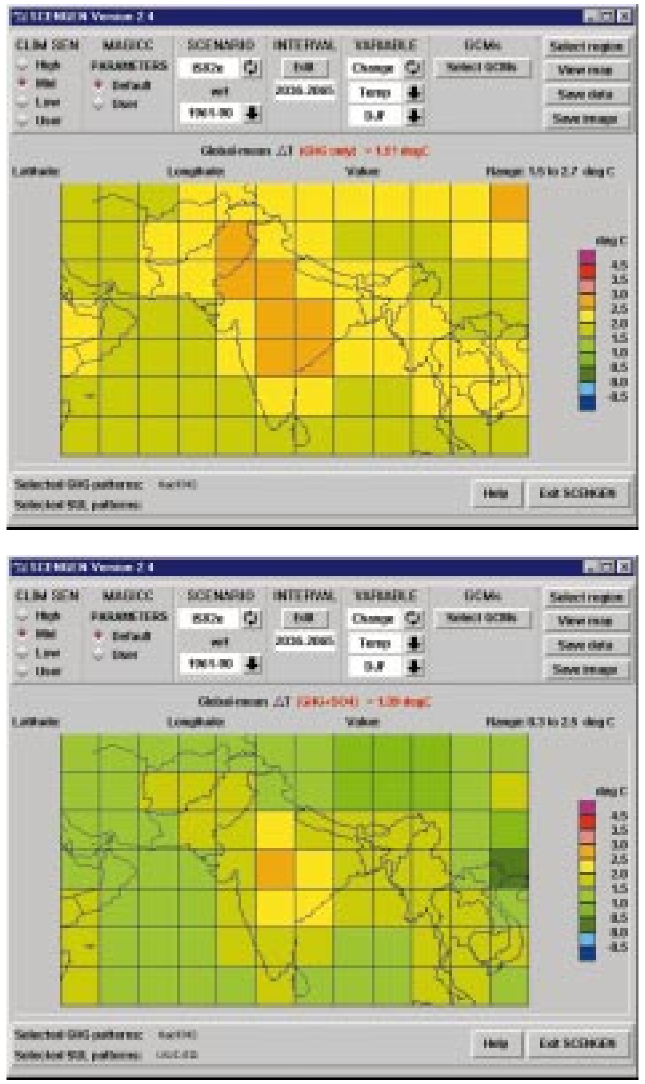


Figure 3.10: *An illustration of uncertainty in the pattern of regional climate change after including the regional effects of sulphate aerosol forcing derived from the UIUC-EQ experiments. The change is in winter (DJF) temperature (°C) for the IS92e emissions scenario and default MAGICC model parameters for the year 2050. (top) HadCM2 greenhouse only; (bottom) HadCM2 greenhouse only, plus UIUC-EQ aerosol pattern.*

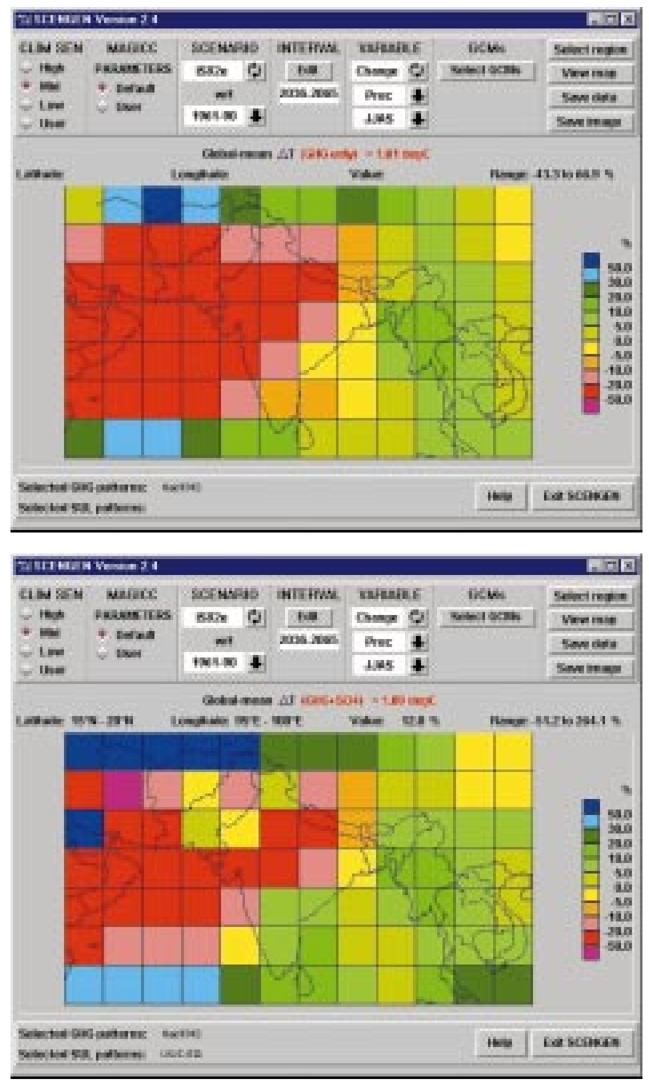


Figure 3.11: *An illustration of uncertainty in the pattern of regional climate change after including the regional effects of sulphate aerosol forcing derived from the UIUC-EQ experiments. The change is in summer monsoon (JJAS) precipitation (%) for the IS92e emissions scenario and default MAGICC model parameters for the year 2050. (top) HadCM2 greenhouse only; (bottom) HadCM2 greenhouse only, plus UIUC-EQ aerosol pattern.*

Box 3.3: Should aerosol effects be included or not?

There are at least two reasons to be cautious in interpreting climate scenarios that include the effects of sulphate aerosols. The first of these is that the magnitude of the direct, and especially the indirect, effect of sulphate aerosols on climate is poorly known. This aspect of radiative forcing has the largest uncertainties of the various anthropogenic forcing agents; the default values in MAGICC are those adopted by the IPCC in its Second Assessment Report, but the recommended range is wide. The second reason to be cautious is that the estimated future aerosol loadings in the IS92 scenarios are now regarded as being unreasonably large. The new SRES emissions scenarios (see Section 5.1, p.39) mostly estimate falling sulphur dioxide emissions in the future, now considered to be more plausible scenarios than the IS92 series. It is also worth noting that the short lifetime of sulphate particles in the atmosphere means that they should be seen as a temporary masking effect on the underlying warming trend due to greenhouse gases. As a final point, we note that it is important to consider the effects of SO_2 emissions and sulphate aerosol forcing, since these may be quite large at the regional scale. The key issue is to keep in mind that there are very large uncertainties associated with this aspect of future climate change.

Whatever choice is made, whether in MAGICC or in SCENGEN (see Section 4.2.4, p.35), it is important that when you report your results you state clearly whether or not aerosol effects have been included in your scenarios.

4: CREATING NATIONAL OR REGIONAL SCENARIOS: AN EXAMPLE FOR BOTSWANA

The previous two sections have described the operation of MAGICC and SCENGEN and indicated the choices available to the user and their associated uncertainty. Here, the whole climate change scenario construction process using MAGICC/SCENGEN is illustrated using Botswana in southern Africa as an example. This example is not intended to be prescriptive on how national climate scenarios should be designed - there are different choices to be made depending on the judgement and experience of the user and on the context and application of the scenarios. These choices are summarised in a schematic way in Figure 4.1. The example shown here is therefore intended to be illustrative only.

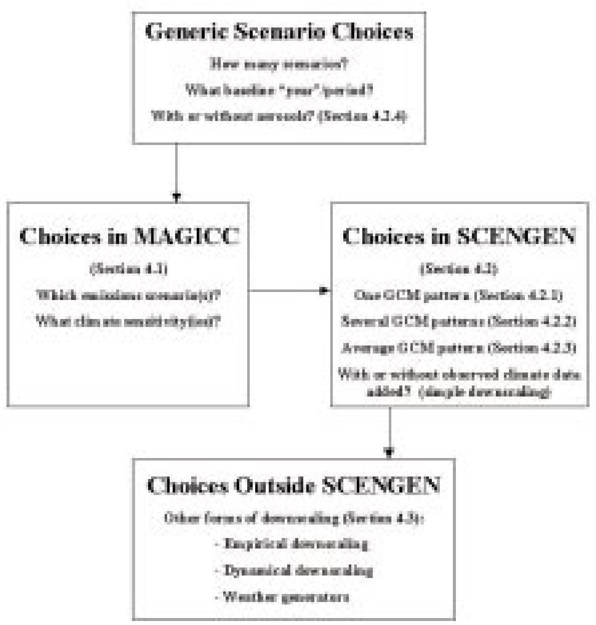


Figure 4.1: *Schematic representation of the choices to be made when designing a set of national climate change scenarios in MAGICC/SCENGEN.*

4.1: Defining the Global-Scale Changes

The first part of the climate change scenario construction process relates to MAGICC and concerns the selection of the emissions scenarios and MAGICC model parameters. In this worked example, we will initially consider the mid-range "reference" scenario, IS92a, and will not make any changes to the default model parameters in MAGICC[17].

Figure 4.2 illustrates the mid-range estimate (climate sensitivity= 2.5°C) and range (corresponding to sensitivity values of 1.5°C and 4.5°C) in global-mean temperature change for the IS92a emissions scenario. By 2050, the global-mean temperature increase according to this scenario may be as little as 0.7°C, or as much as 1.5°C, with a "best" estimate of 1.1°C. The corresponding values for 2100 are 1.5°C, 3.1°C and 2.2°C. These values are all calculated using 1961-90 as the reference period. These global temperature values are passed to SCENGEN and are used to scale the standardised patterns of climate change available in this part of the software. The CO_2 concentrations[18] associated with these projections are shown in Table 4.1.

It is often desirable to consider a wider range of emissions scenarios in V & A assessments, given the uncertainty associated with future greenhouse gas and SO_2 emissions. We also therefore use the IS92e and IS92c emissions scenarios to define a range of global-scale changes in temperature and CO_2 concentration (Table 4.1). Using different combinations of emissions scenarios and climate sensitivities it is possible to define a wide range of possible future global climates. Users are encourage to explore this range and to report and use as wide a range of future outcomes as seems appropriate, rather than focus on the one mid-range outcome. Thus in our example in Table 4.1, one might define three global-scale scenarios as: IS92e emissions with high climate sensitivity; IS92a emissions with mid-range sensitivity; IS92c emissions with low sensitivity. The range of global warming expected by 2100 for these three choices is from 1.0ºC to 3.7ºC[19], with CO_2 concentrations by 2100 ranging from 471ppmv to 949ppmv.

[17] Projections of future sea-level rise are ignored since Botswana is a landlocked state, with an average elevation between 1000 and 1500 metres, and will therefore be unaffected by future changes in sea-level. For different countries, sea-level change would be included as well.

[18] CO_2 concentrations are needed in a variety of agricultural and ecosystem studies and should always be presented alongside scenario changes in climate.

[19] The IPCC Second Assessment Report used 1990 as their reference year and so quoted this range to be from 0.8°C to 3.5°C for warming by 2100, in contrast to the results here which use the 1961-90 period ("year" 1976) as reference. This shows the importance of always quoting the adopted reference period.

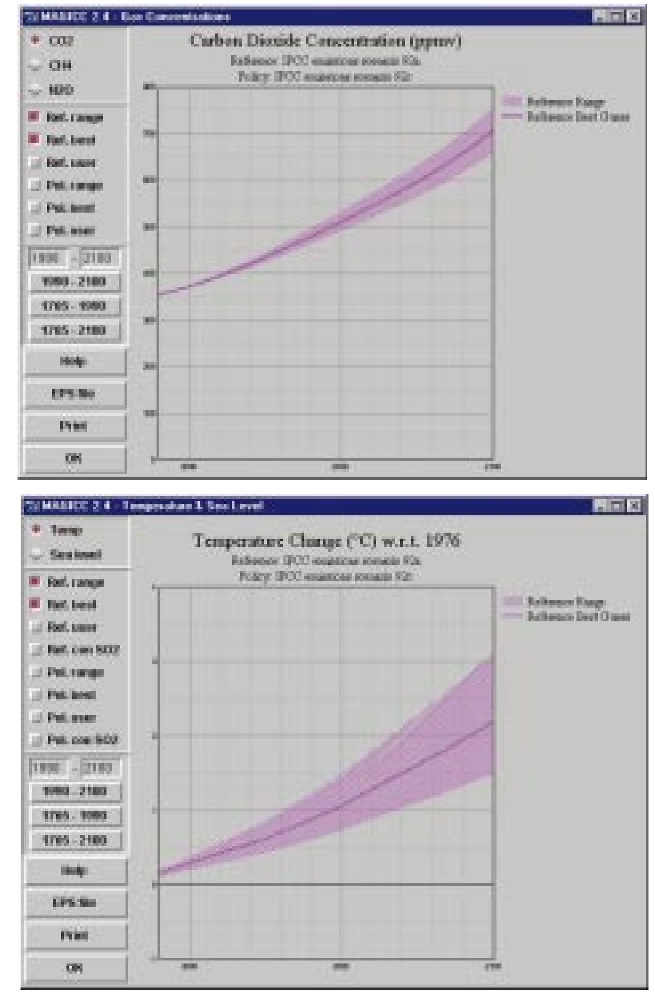


Figure 4.2: *Atmospheric CO_2 concentration (top) and global-mean temperature change (°C; bottom) according to the IS92a emissions scenario. The bold line in the temperature plot indicates a climate sensitivity value of 2.5°C, whilst the shaded area represents the range in global-mean temperature change resulting from low (1.5°C) and high (4.5°C) climate sensitivity values.*

Climate sensitivity	Low	Mid	High	CO_2 concentration
IS92c	1.0	1.5	2.2	471
IS92a	1.5	2.2	3.1	706
IS92e	1.8	2.6	3.7	949

Table 4.1: *Change in global-mean temperature by 2100 (°C) with respect to 1961-90 for three emissions scenarios and for three different climate sensitivities. Aerosol effects included. Also shown are the atmospheric CO_2 concentrations by 2100 (ppmv). The shaded boxes show the values chosen to span the range of global future warming.*

RECOMMENDATION: It is desirable in a V&A assessment to adopt more than a single scenario. The range of scenarios at global-scales can be defined using different combinations of emissions scenarios and MAGICC model parameters - most importantly the climate sensitivity.

4.2: Selecting the Spatial Pattern(s) of Future Climate Change

Once MAGICC has been run with the above options in place, then we proceed to SCENGEN to construct our regional scenarios of climate change for Botswana. For this section, we will illustrate the results for Botswana using the middle of our three global scenarios, namely the IS92a emissions scenarios with a mid-range sensitivity. This yields a global warming (greenhouse gas plus aerosol) of 1.0ºC by 2050 and 2.2ºC by 2100, with respect to 1961-90. However, one should repeat this regionalisation for each of the other two global-scale scenarios highlighted in Table 4.1 to generate a range of future climate changes for Botswana.

As described in Section 2 (p.7), we can select which scenario years we wish to view, and, most importantly, the spatial pattern of climate change we wish to use. The latter can be selected from one of the sixteen GCM patterns of regional greenhouse gas-induced climate change available. In addition to these greenhouse gas-induced patterns, SCENGEN also contains patterns of regional climate change representing the effects of sulphate aerosols on climate. Hence, we can also decide whether or not to include the regional effects of sulphate aerosols in our scenario of climate change for Botswana. We are therefore faced with a number of options when it comes to selecting the pattern of global warming to use:

- **Option 1:** A single GCM can be used to represent the spatial pattern of climate change. However, selecting a single pattern of change "locks" the user into a single representation of future climate and there are different ways of choosing which GCM pattern to use.
- **Option 2:** A number of patterns from different GCMs can be used to represent the range of future regional climate change. A minimum of three different GCM patterns, for example, could be used to represent the possible range of future regional climate change. A national V&A assessment that makes use of all three patterns will be of more value than one which has used only a single pattern of change. Indeed, there may be an advantage in some cases in defining many regional patterns of climate change from as many GCMs as is possible and using all of them separately in a V&A assessment.

- **Option 3:** A composite pattern of climate change can be constructed by averaging either some or all of the GCMs available in SCENGEN (see Box 2.7, p.19). Although this method may be considered to give the average pattern of regional climate change, there are some caveats associated with its use. By averaging GCM change fields, the resulting field is not necessarily an internally-consistent representation of future climate. For example, the GCM-average changes in precipitation and solar radiation may not actually be consistent with each other. This approach again provides only a single pattern of climate change, although this GCM-average pattern might be considered to give a better representation of regional anthropogenic climate change than the pattern derived from any single GCM.

In this example shown here, all three options are considered in order to examine the effects on the resulting scenarios of climate change for Botswana. The effects of sulphate aerosol forcing on the regional pattern of climate change are also demonstrated (Section 4.2.4, p.35), by combining the aerosol-induced patterns of change with the greenhouse gas-induced pattern for the GCM experiment selected in Option 1 above.

The observed 1961-90 mean monthly temperature and precipitation data were saved for the region of Botswana (see Section 2.2.3, p.18, for instructions on how to save data). Since the available observed climate data set in SCENGEN for this region is at relatively high resolution (0.5° latitude/longitude), we decided to construct the climate scenarios for the 0.5° grid cell containing Botswana's capital city - Gaborone (24.75°S, 25.95°E). The 1961-90 observed mean monthly temperature and precipitation for this grid cell are illustrated in Figure 4.3.

The standardised GCM change fields were scaled in SCENGEN by the global-mean temperature change derived from MAGICC for the IS92a emissions scenario and for the year 2050 - about 1.4ºC global warming for greenhouse gas forcing only (just over 1ºC if aerosol effects are included). In order to determine those GCMs that define the extreme changes for Botswana (i.e., the warmest-coolest, wettest-driest), the annual-average changes in mean temperature and precipitation for each GCM were saved, imported into Microsoft Excel, and then plotted (Figure 4.4). Although we chose to use the annual-average changes to define the extreme range of GCM patterns for Botswana, it would also be possible to use the seasonal changes to make this selection. Once the appropriate GCM selections had been made (see below), mean monthly temperature and precipitation changes were saved for the 5° latitude/longitude resolution grid box containing Gaborone, and these changes were then applied to the observed data shown in Figure 4.3, again using Excel[20].

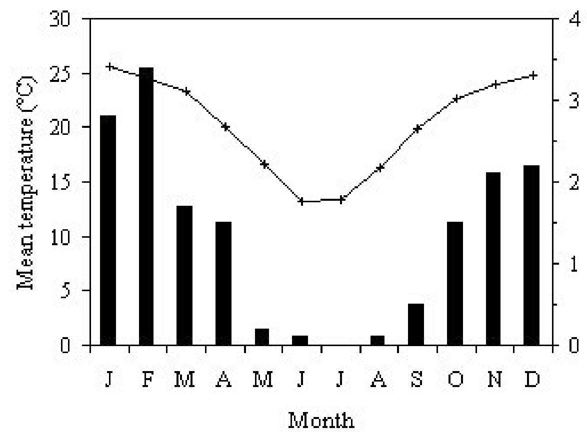


Figure 4.3: *1961-90 observed mean monthly temperature (°C) and precipitation (mm/day) for the 0.5° latitude/longitude grid box containing Gaborone, Botswana (24.75°S, 25.95°E). Precipitation values are indicated in the bar chart, whilst the continuous line represents mean temperature.*

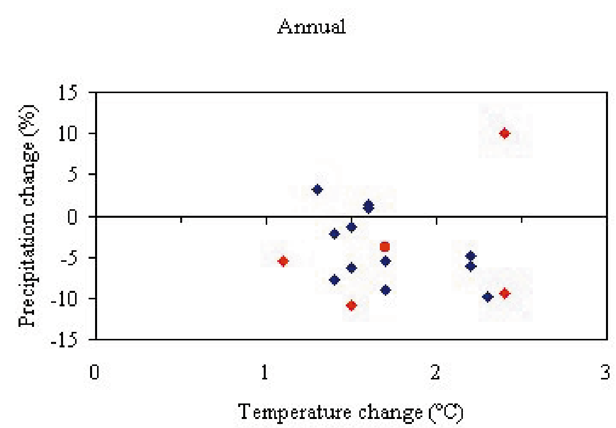


Figure 4.4: *Annual-average mean temperature and precipitation changes corresponding to the IS92a emissions scenario and for the year 2050 for the 5° latitude/longitude grid box containing Gaborone, Botswana. The extreme changes are indicated by red diamonds and correspond to CSIRO-TR (driest), HadCM2 (wettest), CSIRO-EQ (coolest) and HadCM2 and CGCM1 (warmest), whilst the circle indicates the full model-average scenario.*

4.2.1: Constructing a Climate Scenario using a Single GCM Change Pattern

Option 1 for the construction of our Botswana climate scenario considered using only a single GCM to represent the pattern of future climate change. How may this pattern be selected? First, the chosen GCM should be able to adequately simulate present climate conditions, since more confidence may be placed in the climate change simulations from those GCMs which are better able to simulate current climate (although see Box 2.6, p.19). A second consideration is the age of the GCM experiment. Over time, improvements have been made to the model physics, to the model parameterisation schemes, and to the spatial resolution of the GCMs, and increases in computing power have meant that experiments using coupled atmosphere-ocean GCMs have been possible.

Using these two criteria, we select the CSIRO-TR experiment - as well as being one of the more recent GCM experiments listed, it is also one of the better models for simulating present-day average global precipitation patterns (cf. the list of selection criteria in Box 3.2, p.27). Figure 4.5 illustrates the summer (DJF) mean temperature and precipitation CSIRO-TR change fields for the southern Africa region including Botswana. The mean temperature and precipitation annual cycles for this scenario for the grid cell containing Gaborone are illustrated in Figure 4.6. This scenario indicates increases in temperature in all months and decreases in precipitation in all months except August and December.

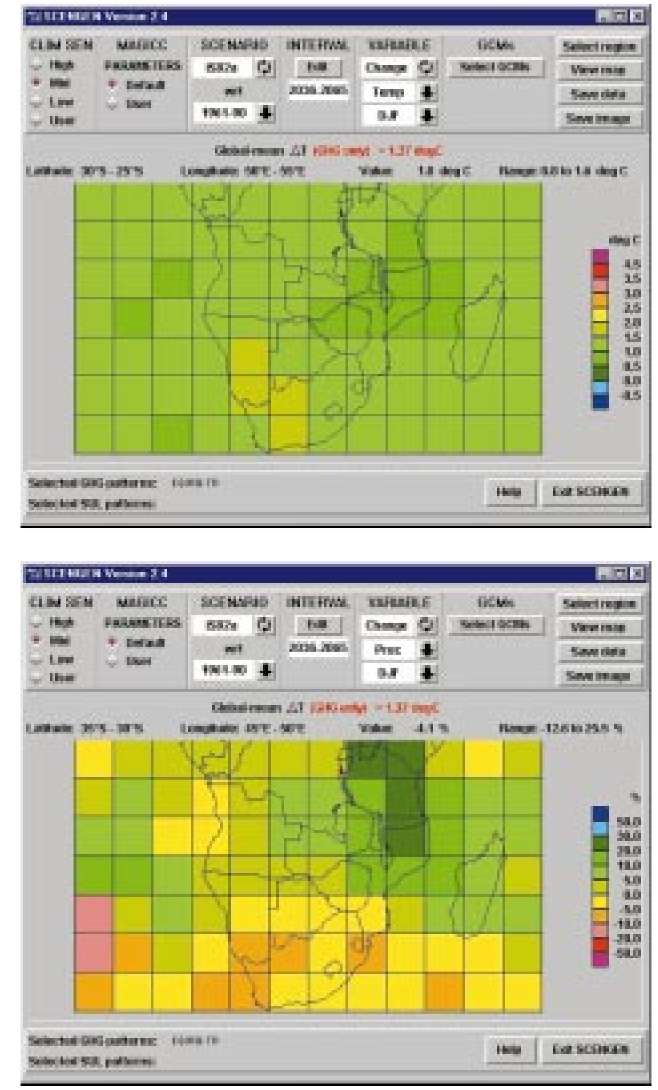


Figure 4.5: *The HadCM2 mean temperature (°C; top) and precipitation (%; bottom) change fields scaled according to the IS92a emissions scenario and a climate sensitivity of 2.5°C for the year 2050 and for the summer (DJF) season. No aerosol effects included.*

4.2.2: Constructing Climate Change Scenarios using Several GCM Change Patterns

In Figure 4.4, four GCM experiments were identified as spanning the range of future climate change over Botswana, based on annual-average values, for our IS92a emissions scenario and a climate sensitivity of 2.5°C for the year 2050. Thus, CSIRO-TR indicated the largest precipitation decreases, HadCM2 the largest precipitation increases, CSIRO2-EQ the smallest temperature increases and HadCM2 and CGCM1 the largest temperature increases. The corresponding annual cycles for mean temperature and precipitation for the Gaborone grid cell for 1961-1990 and then for 2050 are shown in Figure 4.7 (p.34). HadCM2 and CGCM1, indicating the largest annual-average increase in temperature (2.4°C), generate very similar annual temperature cycles for 2050. Although the HadCM2 experiment indicates the largest annual average increase in precipitation, it does not exhibit the largest precipitation

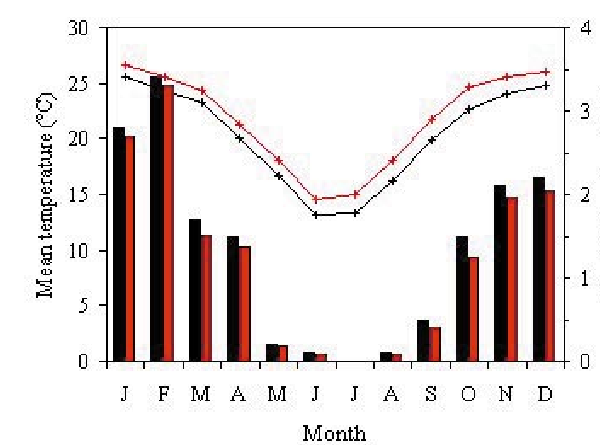


Figure 4.6: *Mean temperature (°C) and precipitation (mm/day) for the 0.5° latitude/longitude grid box containing Gaborone, Botswana (24.75°S, 25.95°E). Observed 1961-90 values are indicated in black (cf. Figure 4.3), whilst red corresponds to the scenario constructed using the CSIRO-TR pattern, scaled according to the global-mean temperature change for the IS92a emissions scenario and a climate sensitivity of 2.5°C for the year 2050. Precipitation values are indicated in the bar chart, whilst the continuous line represents mean temperature. No aerosol effects are included.*

[20] This procedure can be followed in SCENGEN using various map display options, but it is more efficient to export the data to Excel to create the plots shown in this example.

increase in all months. CSIRO-TR, the model with the largest drying on an annual-average basis, actually generates larger precipitation amounts than the HadCM2 scenario through mid-summer to the end of autumn. This analysis demonstrates why it is important to consider the results from more than one GCM experiment when making a full assessment of the possible impacts of climate change.

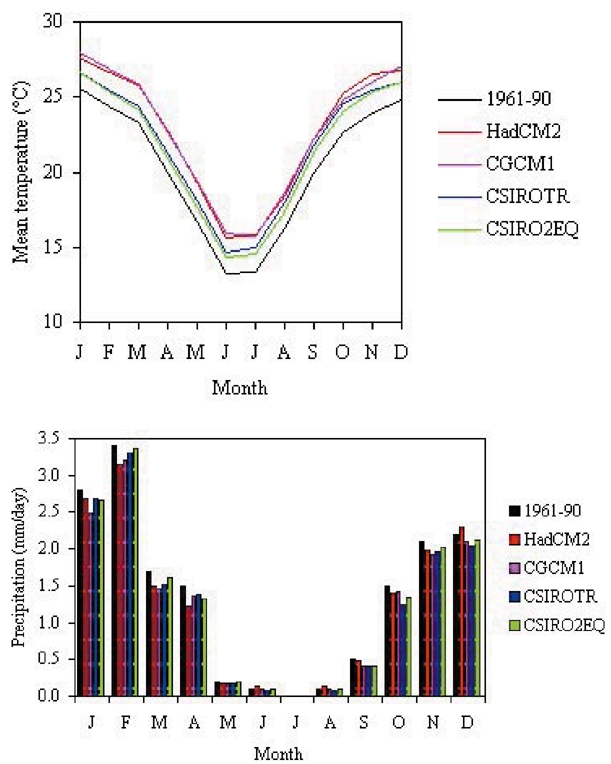


Figure 4.7: *Observed (1961-90) and scenario mean temperature (°C; left) and precipitation (mm/day; right) values for the 0.5° latitude/longitude grid box containing Gaborone, Botswana (24.75°S, 25.95°E). The scenario values are derived from scaling the appropriate patterns according to the global-mean temperature change for the IS92a emissions scenario and a climate sensitivity of 2.5°C for the year 2050.*

4.2.3: Constructing a Climate Change Scenario using a GCM-average Change Pattern

Following Option 3, all the sixteen GCM patterns were averaged to obtain a mean pattern of future climate change. The resulting mean temperature and precipitation annual cycles for the Gaborone grid cell for 1961-90 and for 2050 are indicated in Figure 4.8. As suggested by Figure 4.4 (p.32), the averaging of the sixteen GCM patterns of change yields a decrease in mean-annual precipitation of nearly 4 per cent and an increase in mean temperature about 1.7ºC. Figure 4.9 puts these GCM-composite scenario changes into the context of the scenario changes generated in Section 4.2.2 (p.33) and Figure 4.10 illustrates the winter and summer changes in mean temperature and precipitation for the southern Africa region for this GCM-composite scenario.

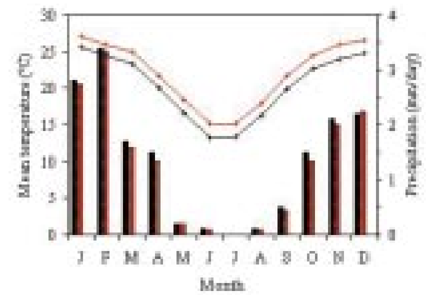


Figure 4.8: *Observed (1961-90) and composite mean temperature (°C) and precipitation (mm/day) values for the 0.5° latitude/longitude grid box containing Gaborone, Botswana (24.75°S, 25.95°E). Observed 1961-90 values are indicated in black, whilst red corresponds to the scenario constructed using the composite pattern scaled according to the global-mean temperature change for the IS92a emissions scenario and a climate sensitivity of 2.5°C for the year 2050. Precipitation values are indicated in the bar chart, whilst the continuous lines represent mean temperature.*

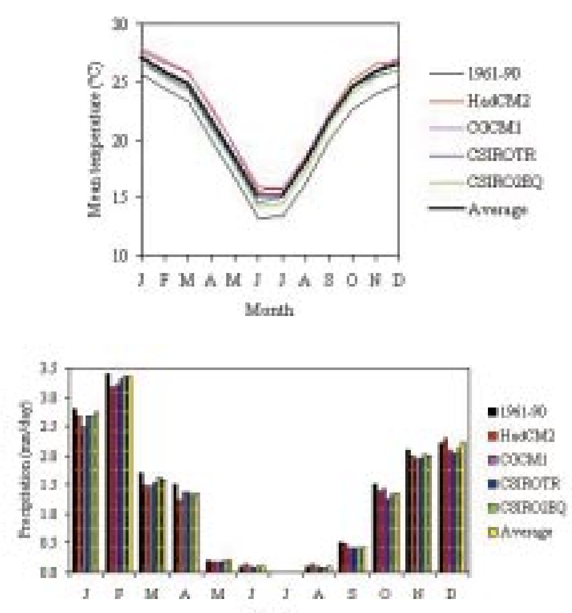


Figure 4.9: *As Figure 4.7, but with the GCM-composite (temperature) and GCM-composite (precipitation) patterns added.*

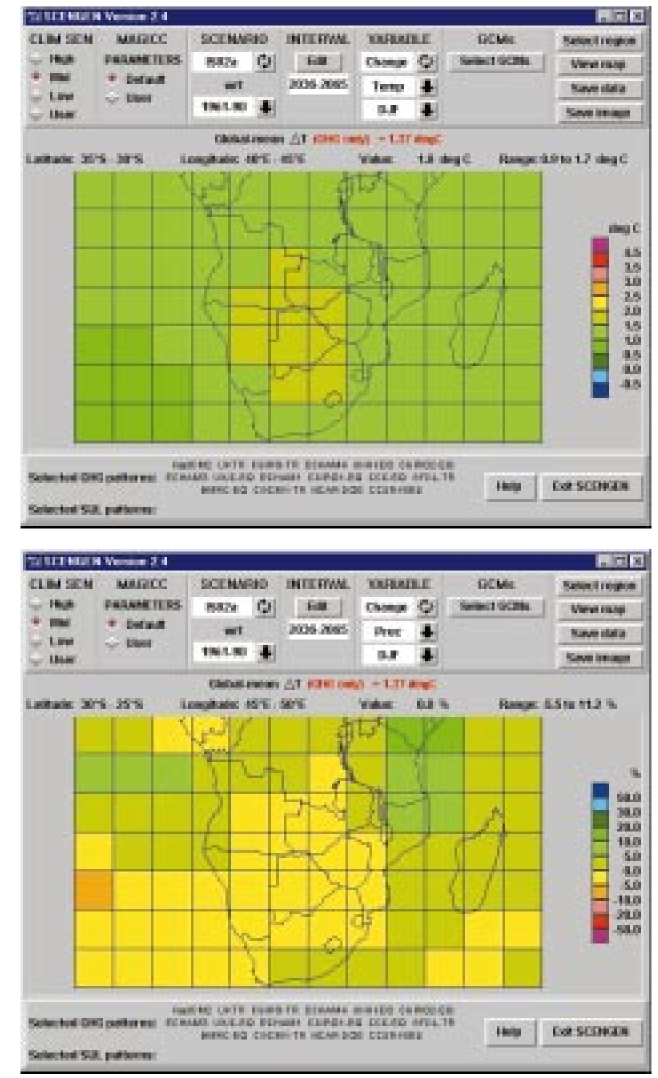


Figure 4.10: *The GCM-composite mean temperature (°C; top) and precipitation (%; bottom) change fields scaled according to the IS92a emissions scenario and a climate sensitivity of 2.5°C for the year 2050 for the summer (DJF) season. No aerosol effects included.*

RECOMMENDATION: Regional climate scenarios derived from a number of GCM patterns of change are preferable to scenarios derived from a single GCM. If time and resources permit, multiple scenarios should be designed and applied in V&A assessments where these scenarios derive from different GCM patterns. There may be some good reasons for designing regional scenarios using a GCM-composite pattern, but these GCM-composite patterns should always be compared with the patterns of change obtained from a range of individual GCMs.

4.2.4: Accounting for the Regional Effects of Sulphate Aerosols

Finally, we consider the regional effects of sulphate aerosol forcing on the pattern of greenhouse gas-induced climate change. In this case, we combine the aerosol-induced pattern of change as defined by the University of Illinois at Urbana-Champagne GCM (UIUC-EQ) with the HadCM2 pattern of greenhouse gas only-induced climate change for our IS92a emissions scenario for the year 2050 (as illustrated in Section 4.2.1, p.32, and Figure 4.5, p.33). Note that the global warming by 2050 after allowing for aerosol effects is now just over 1ºC rather than 1.4ºC when only greenhouse gas forcing was considered. The winter (JJA) mean temperature and summer (DJF) precipitation change fields are illustrated in Figure 4.11, (p.37), and the mean temperature and precipitation annual cycles for the Gaborone grid cell for 1961-90 and 2050 are shown in Figure 4.12, (p.37). The inclusion of the sulphate aerosol effect has a greater effect on regional precipitation than it does on regional temperature. Over Botswana, the aerosol effects slightly reduce the rate of warming, but only in some winter and spring months (i.e., June, July, September, October), whereas the aerosol effects change the sign of the precipitation change in some months. For example, January in Gaborone becomes drier with greenhouse gas only climate change, but becomes wetter when aerosol effects are included.

RECOMMENDATION: It may not always be desirable or necessary to design regional climate scenarios that include the effects of sulphate aerosols (see Box 3.3, p.29). No general rule can be applied here. Regional effects of sulphate aerosols may sometimes be large (e.g. over parts of southeast Asia) and sometimes be small (e.g. over much of the Southern Hemisphere, although here the effects of biomass aerosols may be large for some regions). Aerosol effects on climate are generally less well-defined than are the effects of greenhouse gas forcing.

REMEMBER: The aerosol forcing in most of the old IS92 emissions scenarios is now generally believed to be substantially exaggerated in most regions (see Section 5.1, p.39).

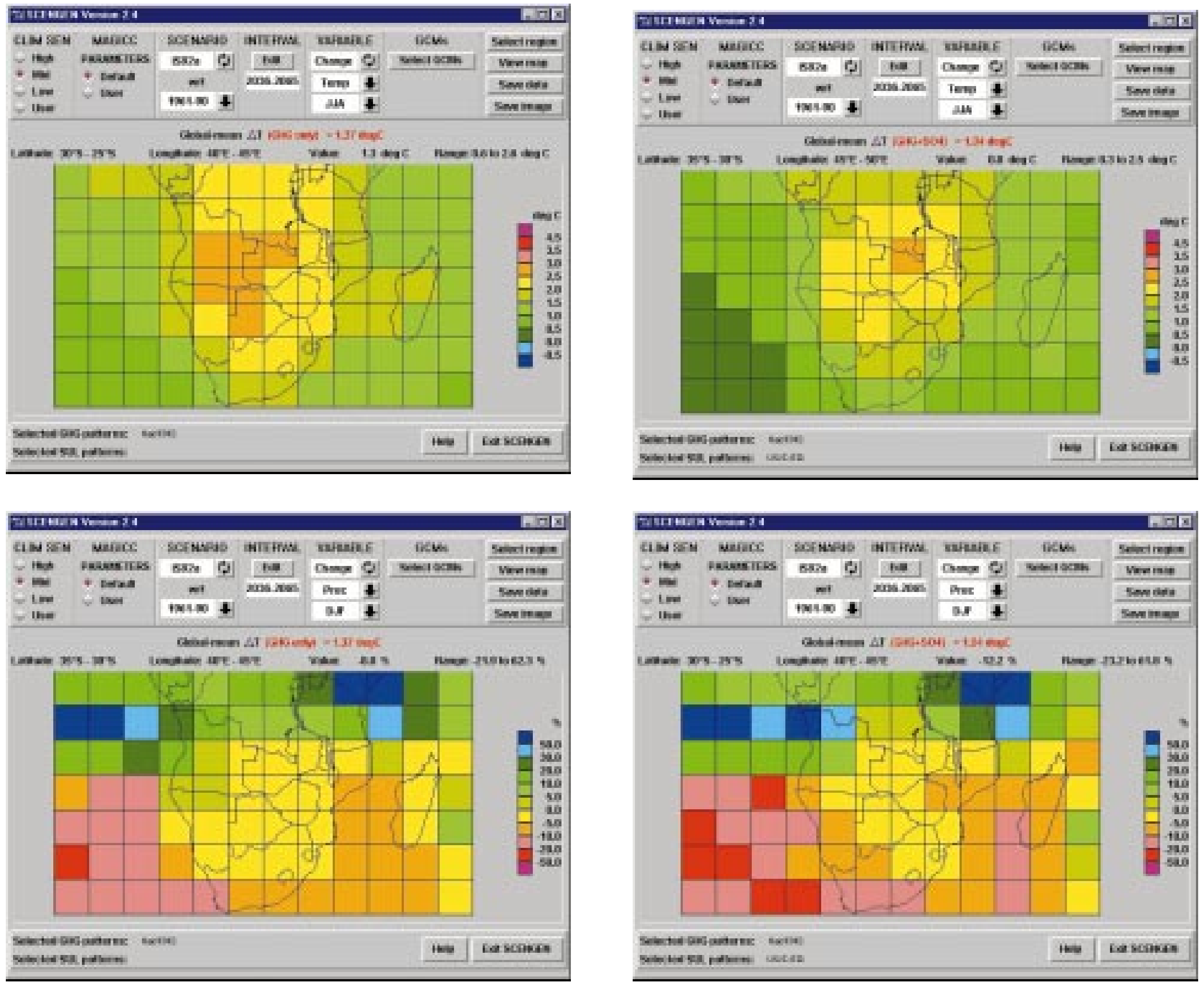


Figure 4.11: *The effect of including aerosol-induced climate change in a regional climate change scenario. Mean temperature (°C) and precipitation (%) change fields for the HadCM2 greenhouse gas only experiment (left), combined with the regional aerosol-induced changes from the UIUC-EQ GCM sulphate aerosol experiment (right). All fields are scaled according to the IS92a emissions scenario and a climate sensitivity of 2.5°C for the year 2050: (top) winter (JJA) temperature; (bottom) summer (DJF) precipitation.*

This section has illustrated, for an example in Botswana, the effects of using patterns of climate change derived from a single GCM experiment, from several experiments in order to span the probable future range of climate change, and from averaging the patterns from all available GCM experiments. It has also illustrated the effect on the climate scenario being constructed of including the regional effects of sulphate aerosol forcing.

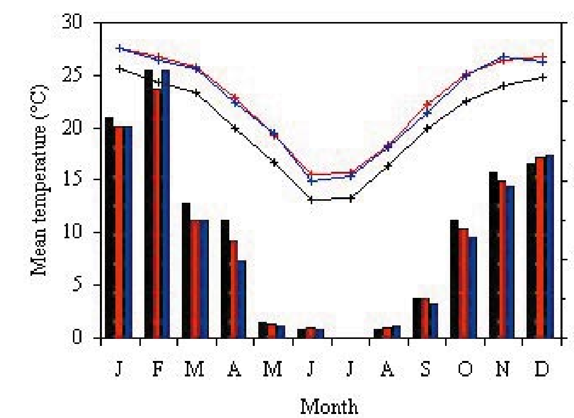


Figure 4.12: *The effect of including sulphate aerosol forcing on the HadCM2 climate scenario for the IS92a emissions scenario for the year 2050. Mean temperature (°C) and precipitation (mm/day) for 1961-90 observed (black), the HadCM2 global warming scenario (red), and the HadCM2 scenario including the regional effects of sulphate aerosols as defined by the UIUC-EQ GCM experiment (blue), for the grid cell containing Gaborone, Botswana (24.75°S, 25.95°E).*

4.3: Obtaining Finer Resolution Climate Change Scenarios - Downscaling

Results from General Circulation Models provide the most credible basis for developing scenarios of future climate change for national or regional V&A assessments. The information from GCMs, however, is resolved at generally very coarse scales, at best around 3º latitude/longitude (~330km at the equator), and for some models more like 4º latitude/longitude. SCENGEN provides climate change fields at 5º latitude/longitude resolution, interpolated from GCM resolutions. This coarse spatial resolution of GCM-based climate change scenarios is therefore at first sight a major limitation in their application to a wide range of impact assessments. These assessments may either be quite localised - around a single river catchment or urban area - or may operate on a national scale, but with a spatial resolution of kilometres or tens of kilometres rather than hundreds of kilometres - for example a national land use classification assessment.

How can such GCM-based information be made more useful in such impact assessments? The answer to this question requires some consideration of the problem of "downscaling" climate change information. A useful review of downscaling methods is provided by Wilby and Wigley (1997) and a full assessment of downscaling[21] methods will be provided in Chapter 10 of the Working Group I Report of the IPCC Third Assessment Report (Giorgi *et al*., 2001).

One of the simplest ways of adding spatial detail to GCM-based climate change scenarios is to interpolate the GCM-scale changes to a finer resolution (e.g. 0.5º latitude/longitude or 50km) and then combine these interpolated changes with observed climate information at the fine resolution. This approach is here termed "simple" downscaling because no new meteorological insight is added to the GCM-based changes and the basic spatial pattern of present climate is assumed to remain largely unchanged in the future. This approach is easy to apply and allows impact assessment models to use climate scenarios at a resolution that would otherwise be difficult or costly to obtain. This is the approach to downscaling taken in SCENGEN. SCENGEN-derived climate change scenarios can be combined outside SCENGEN with a variety of daily and monthly observational climate data for site locations, catchments or grid cells (see example in Figure 4.13).

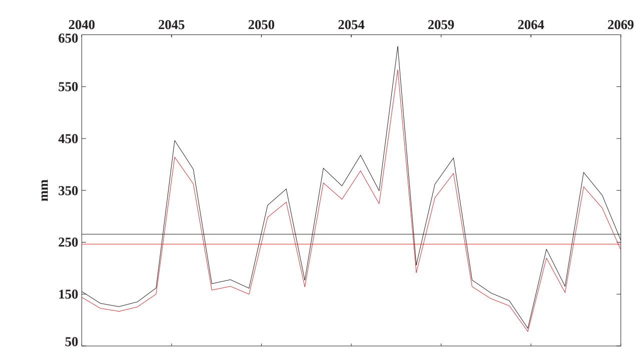


Figure 4.13: *An example of applying a SCENGEN-derived climate change scenario to an observed monthly rainfall time series for Gaborone in Botswana. Here, the observed station time series for 1961-90 (black) is perturbed by a climate change scenario for the "year" 2050, assuming the IS92a emissions scenario and the CGCM1 GHG-only climate change pattern (no aerosol effects). A fixed decrease of 7.2% is applied to this summer (DJF) rainfall series generating a new rainfall series for the period 2035-2064 (red). Horizontal lines show the 30-year average rainfall.*

[21] Note: IPCC prefer the more generic term "regionalisation" to downscaling.

A more sophisticated approach to the problem uses statistical downscaling methods. There are at least three broad clusters of methods within this general category - regression methods, circulation typing schemes, and stochastic weather generators. Developing a statistical downscaling model is usually quite time-intensive and will always require very extensive observational data - daily / hourly weather data for the surface, and maybe for the upper air, and usually data for several / many sites or grid boxes covering the region of interest. Most statistical downscaling models are developed with a specific application in mind - whether agriculture, forestry, water, etc. - and quite often for a specific geographic region. Stochastic weather generators[22] are quite often used in all three of these cited climate change impact areas and a good review of weather generators is provided by Wilks and Wilby (1999). Not all statistical downscaling methods can easily be transported from one region to another. Statistically-downscaled regional climate scenarios depend on the validity of the GCM output, on the assumption that large-scale / small-scale weather relationships do not change in the future and, sometimes, that the internal relationships between difference climate variables do not alter in the future.

A third downscaling option is to use a higher resolution limited-area model (often called a Regional Climate Model - RCM). Such RCMs typically cover an area the size of southern Africa or Europe, have a spatial resolution of between 25km and 50km, and are driven by boundary conditions obtained from a GCM climate change experiment. Just because results from RCM experiments show greater climate detail than do GCMs, this does not automatically qualify RCM-based scenarios as any more “accurate”. The most important limitation to the regional climate modelling approach is that the RCM is completely dependent upon the boundary conditions extracted from the GCM experiments to drive the regional atmosphere. If the GCM simulation of climate change is inaccurate than so will the RCM-based scenario. RCMs still require considerable computing resources and may be as expensive to run as a GCM.

The situation of small island states in relation to downscaling climate scenarios is usually quite different from mainland states because small islands are not represented in GCMs. Changes in climate simulated by these models for such regions are therefore usually representative of the open ocean; local island topographic effects on climate are not captured by the models. First-order estimates of climate change for small islands may still be derived from GCMs (e.g., as also done in the VANDACLIM or PACCLIM climate scenario generators; Annex C), but caution should be exercised when interpreting their results.

Downscaling may also be necessary for information regarding sea-level rise. Downscaling approaches using global (or even regional-mean) sea-level changes need to consider the interaction between any change in mean sea-level and shoreline erosion rates, the local tide regimes, changes in storm regimes and bathymetry.

4.3.1: Value for Effort

Since all downscaling methods are reliant in some way upon the results from GCM experiments, the value of always investing a lot of extra effort in downscaling procedures should be questioned by teams involved in V&A assessments. The confidence associated with any individual GCM experiment may already be low, and although downscaling methods may introduce extra precision into a climate scenario, they do not necessarily introduce extra accuracy. Since there is a wide range of downscaling methods available, the application of any one downscaling method in a scenario application introduces further unquantified uncertainties into the climate scenario. Ideally, one would like to apply several downscaling methods to the results of several GCM experiments in order to assess the relative importance of the uncertainties involved. Such an ambitious objective has rarely been achieved in any studies to date (see Wilby *et al*., 1999, for one example). It seems sensible therefore to fully exploit the GCM information which exists at its original resolution (i.e., that can be obtained from a scenario generator such as SCENGEN) and then, if it is thought necessary, to pursue higher resolution studies.

> RECOMMENDATION: SCENGEN uses a very “simple downscaling” method by combining coarse resolution GCM changes with higher resolution observed climate data. Whether or not additional downscaling procedures can or should be employed depends very much on the application and the resources and data available. Useful national and / or regional climate scenarios and impact assessments can be made by combining SCENGEN-derived climate change scenarios with a variety of daily and monthly observational climate data without the need for additional downscaling.

22 Annex D provides references to two public-domain weather generators.

5: OTHER APPLICATIONS OF MAGICC/SCENGEN

MAGICC is designed so that updates and additions to the library of emissions scenarios can easily be made, either by editing existing scenarios or by creating a new emissions scenario (see Section 2.1, p.7). The climate implications of new emissions scenarios can then be viewed at either the global (MAGICC) or national / regional (SCENGEN) scales. In this final section, we will examine two other applications of MAGICC / SCENGEN which illustrate: the climatic effects of new greenhouse gas and sulphate aerosol emissions futures; and the effects of reducing CO_2 emissions in order to meet the concentration stabilisation objective of Article 2 of the UNFCCC.

5.1: The Implications of the IS92 and Draft SRES Emissions Scenarios

In the IPCC Second Assessment Report (IPCC, 1996), the six IS92 scenarios (originally described in Leggett *et al*., 1992) were adopted to represent the range of greenhouse gas and sulphur dioxide emissions futures thought to be most likely at that time. For the IPCC Third Assessment Report, a Special Report on Emissions Scenarios (SRES) was commissioned. This report had not finally been approved at the time MAGICC / SCENGEN Version 2.4 was finalised, although it is scheduled for publication in June 2000 (IPCC, 2000). The new SRES report contains 40 different emissions scenarios spanning a slightly larger range of emissions than the old IS92 series. The new SRES emissions scenarios have implications for the V&A studies as national teams will have a wider selection of emissions scenarios from which to choose.

In accordance with a decision of the IPCC Bureau in 1998 to release draft emissions scenarios to climate modellers, one SRES Marker scenario was chosen from each of the scenario groups based on the four storylines. These Marker scenarios were termed: A1[23], A2, B1, and B2. The choice of the Markers was based on which of the initial quantifications best reflected the respective storyline and on the different features of specific energy-economic models used to generate the emissions. Marker scenarios are no more or less likely than any other scenarios, but these scenarios have received the closest scrutiny. It is these four draft SRES Marker emissions scenarios that are included in Version 2.4 of MAGICC / SCENGEN.

The four SRES storylines can be summarised as follows[24]:

- SRES A1: In this story the pursuit of personal wealth is more important than environmental quality. There is very rapid economic growth, low population growth and new and more efficient energy technologies are rapidly introduced.
- SRES A2: The underlying themes of this story are the strengthening of regional cultural identities, an emphasis on family values and local traditions, high population growth and less concern for rapid economic development.
- SRES B1: A move towards less materialistic values and the introduction of clean technologies are emphasised in this story. Global solutions to environmental and social sustainability are sought, including concerted efforts for rapid technology development, dematerialisation of the economy and improving equity.
- SRES B2: In this story the emphasis is on local or regional solutions to economic, social and environmental sustainability.

Figure 5.1 illustrates the future CO_2 and SO_2 emissions associated with each of the six IS92 and four draft SRES emissions scenarios. The extreme range of future CO_2 emissions is bounded by the IS92c and IS92e emissions scenarios. The SRES scenarios have very much lower SO_2 emissions than the IS92 series, and for A1, B1 and B2 sulphur emissions fall to well below 1990 levels by 2100. This represents a major difference in thinking about the future between the IS92 and SRES sets of scenarios and means that in three of the SRES scenarios the effect of including sulphate aerosol forcing is to introduce additional warming of climate relative to 1990, whereas in the IS92 scenarios aerosol forcing led to a cooling of climate relative to 1990.

The global-mean temperature and sea-level changes associated with the IS92 and SRES emissions scenarios, derived using the default MAGICC parameters, are indicated in Figure 5.2. Box 5.1 summarises these results. Although the draft SRES Marker emissions of CO_2 (and other greenhouse gases) are generally lower than in the IS92 scenarios, the four SRES scenarios generally indicate more rapid increases in global-mean temperature and sea-level than the six IS92 emissions scenarios (Wigley, 1999; Smith *et al*., 2000). The reason for this is the very different sulphate aerosol forcing in the two sets of scenarios as mentioned above.

23 The final SRES report adopts two more emissions scenarios as Markers - A1T and A1F. To distinguish these from the draft A1 Marker, the original A1 scenario is renamed as A1B (to reflect a balanced future energy mix).

24 More details on the draft (January 1999) SRES storylines and emisions scenarios used in Version 2.4 and in this Workbook can be found at: http: / / ipcc-ddc.cru.uea.ac.uk / cru_data / examine / non_climate / non_climateSRES.html

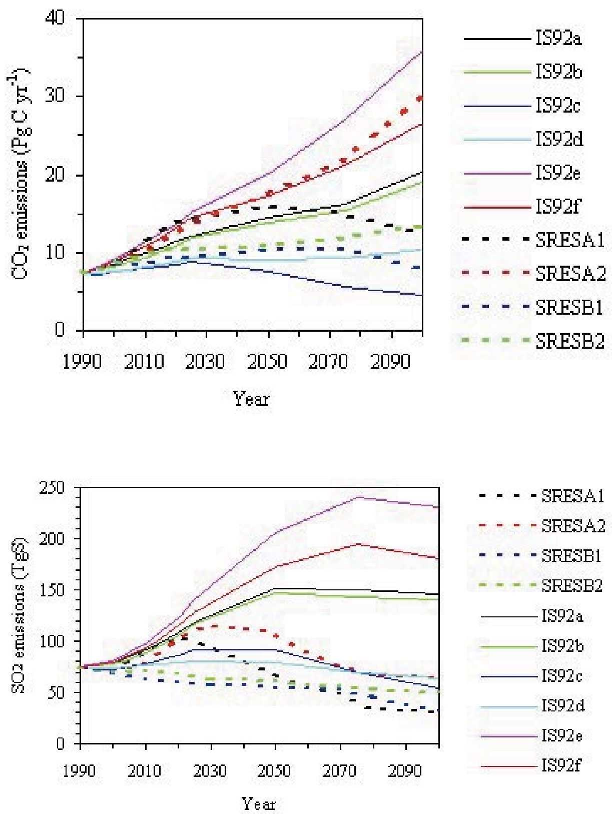


Figure 5.1: *Global emissions of (top)* CO_2*, and (bottom)* SO_2 *for the six IS92 and four draft SRES emissions scenarios.*

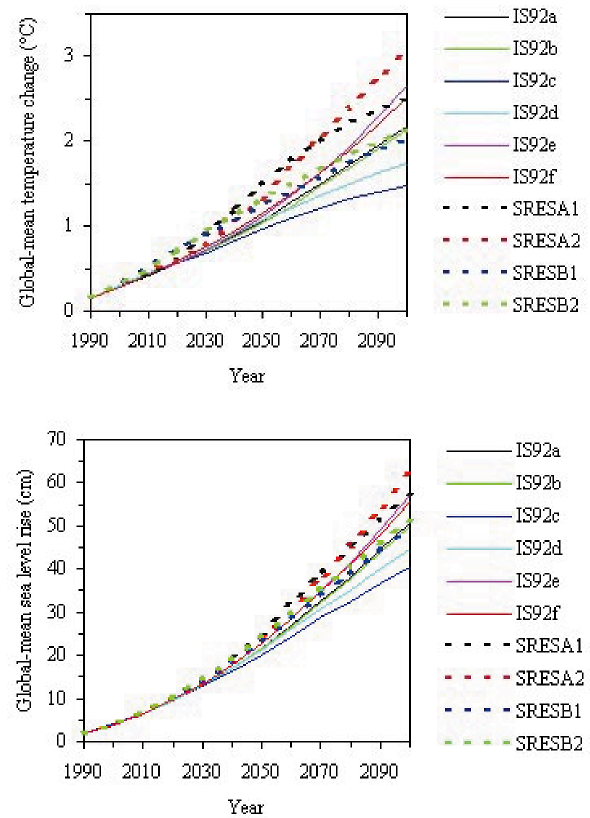


Figure 5.2: *Global-mean temperature (top) and sea-level (bottom) change with respect to 1961-90 for each of the IS92 and draft SRES emissions scenarios, assuming a climate sensitivity of 2.5°C and default MAGICC parameters.*

Box 5.1: How different are the climate changes associated with the IS92 and the draft SRES scenarios?

The range of global warming by 2100 with respect to 1961-90, using the default MAGICC parameters, is from about 1.4°C to 2.6°C under the IS92 scenarios and from about 2.0° to 3.1°C for the draft SRES scenarios. The respective ranges for global sea-level rise in the two sets of scenarios are from 40cm to 57cm and from 49cm to 62cm. Although the SRES greenhouse gas emissions therefore fall within the IS92 range, or are lower, the resulting global temperature and sea-level increases are generally larger for SRES because of the very different assumptions about future emissions of sulphur dioxide and hence sulphate aerosol forcing. These implications can be further explored at a regional level in SCENGEN, using the combination of greenhouse gas and sulphate aerosol induced patterns of regional climate change. The implications of the full set of SRES emissions scenarios can be explored when they are released later in 2000.

5.2: The Kyoto Protocol and Other Emissions Reduction Scenarios

5.2.1: The Kyoto Protocol

The IS92 emissions scenarios (Leggett *et al.*, 1992) did not include any specific climate policy interventions or emissions targets. Such targets have subsequently been set under the Kyoto Protocol, the wording of which was finalised at the Third Conference of the Parties in Kyoto, Japan, in December 1997. The Protocol is currently awaiting ratification. The goal of the Protocol is to begin the process of meeting Article 2 of the UNFCCC through an initial set of emissions reductions targets, specifically a reduction in greenhouse gas emissions by industrialised nations of 5.2%, relative to 1990, by the period 2008-2012.

IMPORTANT: The discussion here is not intended to anticipate the final outcome of the Kyoto Protocol, but to show how MAGICC/SCENGEN can be used to develop various climate scenarios under a given set of assumptions.

Here, the effects of this Protocol on greenhouse gas emissions and global-mean temperature change are examined in relation to the IS92a emissions scenario, following Wigley (1998). Figure 5.3 illustrates the CO_2 emissions for the IS92a[25] and the Kyoto Protocol emissions scenarios, assuming the Kyoto target is met by reducing CO2 emissions alone[26] and that there are no further emissions reductions after 2012 (the K-NOMORE scenario in the MAGICC emissions menu). Under these assumptions, the Kyoto Protocol reduces global carbon emissions by 2100 by less than 1 GtC (see the MAGICC/SCENGEN Technical Manual - Wigley *et al.*, 2000 - for further explanation of these scenarios). The consequences of these Kyoto targets being met for global-mean temperature change are shown in Figure 5.4. Assuming the IS92a emissions scenario is the "reference" case and assuming a mid-range climate sensitivity, the effect of the K-NOMORE scenario on global-mean temperature is to reduce the warming by 2100 by less than 0.1°C, i.e., a warming of slightly more than 2.1°C compared with about 2.2°C under the unabated IS92a emissions scenario.

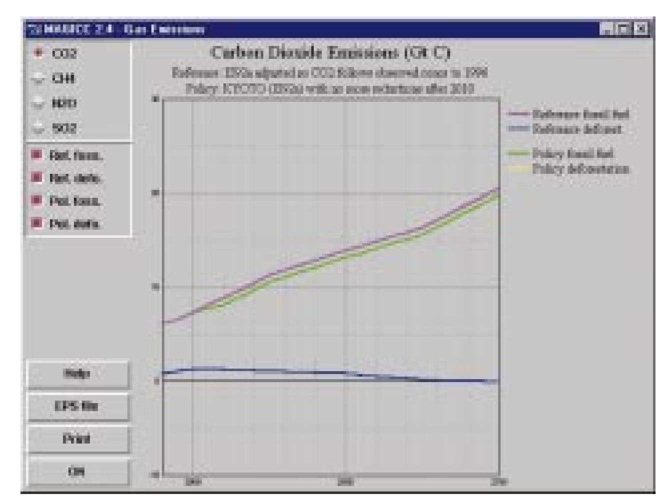


Figure 5.3: *Emissions of* CO_2 *(GtC) for the IS92a and for the Kyoto Protocol (K-NOMORE) emissions scenarios.*

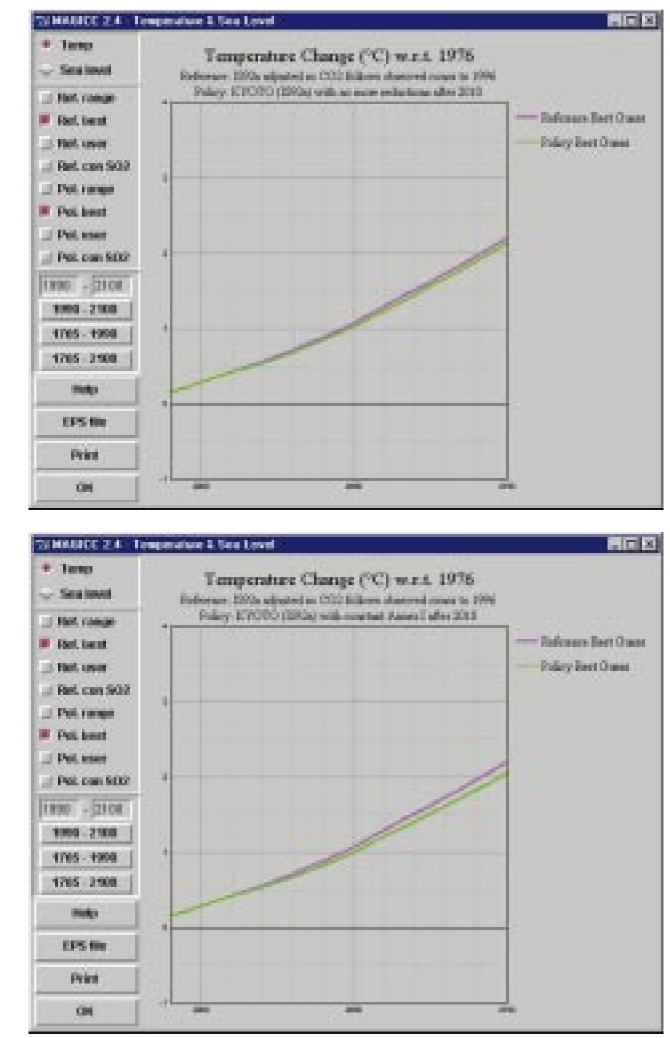


Figure 5.4: *Global-mean temperature change (°C) for the IS92a and Kyoto Protocol (K-NOMORE) emissions scenarios (top) and for the IS92a and the enhanced Kyoto Protocol (K-CON1) emissions scenario (bottom). All calculations assume a climate sensitivity of 2.5°C and the reference period is 1961-90.*

[25] The correct reference scenario to use in this exercise is the IS92aFIT scenario in MAGICC; this is a modification of IS92a to account for measured 1990s emissions data (see Wigley, 1998).

[26] The Kyoto Protocol allows the target to be reached through reductions in the emissions of a range of greenhouse gas - CO_2, CH_4 N_2O, various halocarbons and sulphur hexaflouride (SF_6).

It is also possible to explore the implications of a number of post-Kyoto emissions reductions targets. Again, the following assumptions are for illustrative purposes only and do not presume that any particular set of policies will be implemented. Figure 5.4 (p.41) shows the result of applying one such emissions scenario in MAGICC (K-CON1) in which industrialised country emissions stabilise beyond the Kyoto period at 2012 levels, i.e., there are no further increases in industrialised country emissions. Under this scenario, global carbon emissions by 2100 reduce by a further 1.4GtC (relative to K-NOMORE) and global warming by 2100 is reduced from 2.2°C under the unabated IS92a scenario to just over 2°C.

5.2.2: Other Emissions Reductions Scenarios

MAGICC may also be used to explore the implications for climate of other emissions scenarios, such as scenarios that lead to stabilisation of the concentration of CO_2 in the atmosphere - the ultimate objective of Article 2 of the UNFCCC. We illustrate the effects of two such emissions reductions scenarios that lead ultimately (well after 2100) to CO_2 concentration stabilisation at 550 and 650 ppmv. In the MAGICC emissions menu these scenarios are labelled as WRE550 and WRE650. They correspond to two of the concentration stabilisation emissions profiles developed by Wigley *et al*. 1996; (see also the MAGICC/SCENGEN Technical Manual - Wigley *et al*., 2000 - for further explanation). With unabated IS92a emissions, global-mean temperature by 2100 increases by nearly 2.2°C compared to 1961-90. Emissions scenarios leading to stabilisation of CO_2 in the atmosphere reduce the rate of change of global climate. Under the WRE650 scenario, warming by 2100 is just under 1.9°C and under the WRE550 scenario only about 1.6°C. These stabilisation scenarios reduce sea-level rise by smaller magnitudes than they do global temperature, the 2100 sea-level rise for the three scenarios being, respectively, about 51cm, 47cm and 44cm. Figure 5.5 illustrates the global-mean temperature and sea-level changes for these two stabilisation scenarios compared to the unabated IS92a emissions scenario.

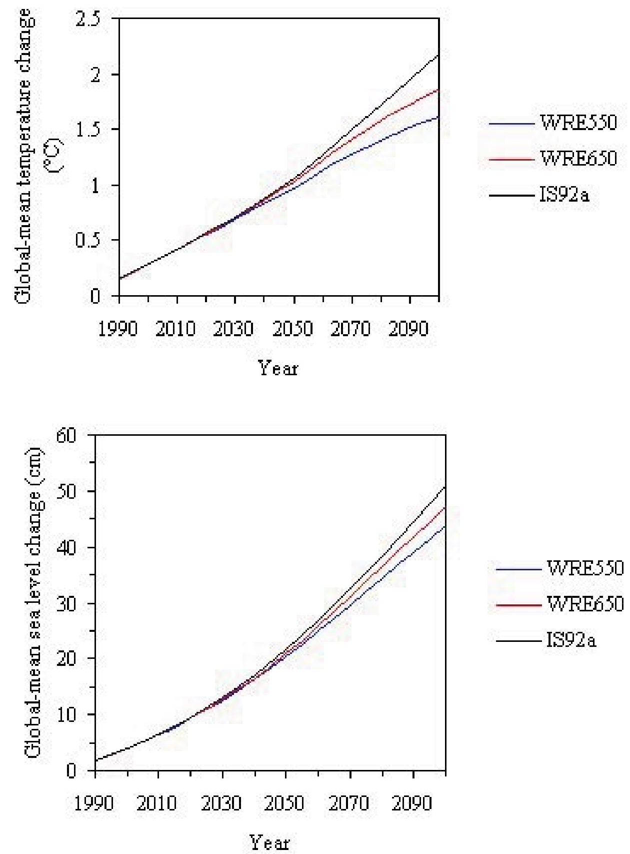


Figure 5.5: *Changes in global-mean temperature (top) and sea-level (bottom) for the two stabilisation emissions scenarios - WRE550 and WRE650 - and also for the unabated IS92a emissions scenario, assuming a climate sensitivity of 2.5°C and a reference period of 1961-90.*

6: CONCLUSIONS

This Workbook has described how the MAGICC /SCENGEN climate scenario generator can be used in the construction of climate change scenarios for regional and national V&A assessments. This CSG draws very closely upon the science and data sets assessed by the IPCC in their Second Assessment Report and in subsequent IPCC Technical Notes. A companion Technical Manual for MAGICC/SCENGEN is also available (Wigley *et al*., 2000).

It is important to note that designing and applying the types of climate change scenarios described here is not the only desirable activity in a national or regional V&A assessment with regard to climate information. For example, it is strongly recommended that teams also use incremental (sometimes called arbitrary) scenarios to test the sensitivity of their impact models and systems to climate change. Sensitivity analysis, when undertaken in conjunction with impacts and adaptation analyses performed using MAGICC/SCENGEN-type climate change scenarios, represents a powerful methodology for V&A assessments. Users are encouraged to read the “Guidelines on the use of scenario data for climate impact and adaptation assessment: Version 1” prepared by the IPCC Task Group on Scenarios for Climate Impact Assessment (TGCIA, 1999) and the UNEP “Handbook on methods for climate change impact assessment and adaptation strategies” (Feenstra *et al*. 1998) for further guidance on methodology. Some suggested reporting standards are listed in Box 6.1.

There are also a number of other CSGs apart from MAGICC/SCENGEN. For example, COSMIC, CLIMPACTS and OZCLIM also offer one or more of the facilities that MAGICC/SCENGEN provides. Access to these is indicated in Annex C (p.49).

Box 6.1: Reporting standards

Throughout this Workbook, a number of suggestions have been made concerning the presentation and reporting of climate change impact assessments, especially concerning the use of climate scenarios. Some of the most important are summarised here based on the TGCIA (1999) guidelines. These are important for improving the transparency of V&A assessments.

Appropriate citation of sources
When using results from MAGICC/SCENGEN Version 2.4 in a report, the correct citation is Wigley *et al.* (2000). Out of courtesy to the scientists involved, the original sources of the observed climate data and GCM experiments used should also be cited correctly. For example, the **Select GCMs** menu in SCENGEN contains the correct sources to cite in referring to different GCMs. Similarly, the sources of emissions scenarios should also be referenced correctly (for example, the source of the IS92 scenarios is Leggett *et al*., 1992). If components of these scenarios are to be applied (for example, regional population projections) then the original source of the projections should be cited (i.e., United Nations, 1992). The IPCC Data Distribution Centre provides guidance on these sources.

Use of standard notation
Special care should be taken to adopt conventional notation when referring to individual GCM experiments. There are many versions of the same or similar models, so it is important to identify models using an accepted acronym. Again, the **Select GCMs** menu in SCENGEN contains the correct sources to cite for different GCMs.

Description of methods
The methods adopted to select, interpret and apply the scenarios should be described in full, with proper citation to comparable previous studies employing similar methods. This information is important for evaluating and comparing different impact studies.

Presentation of results
Impact studies that employ climate scenarios should indicate, where possible, the statistical significance of the results. For example, regional scenarios of climate change should be compared with natural variability in the baseline climate observations or in GCM control simulations. Similarly, the impacts of the climate change scenarios should, where possible, be contrasted with the impacts of natural climate variability.

Consideration of uncertainties
At each stage of an impact assessment, there should be a full and proper discussion of the key uncertainties in the results, including those attributable to the input data, impact models, climate scenarios and non-climatic scenarios (Carter *et al*., 1999). A rigorous sensitivity analysis can be very helpful in identifying some of the major uncertainties. It is also recommended that users should design and apply multiple scenarios in impact assessments, where these multiple scenarios span a range of possible future climates, rather than designing and applying a single “best-guess” scenario.

Some Limitations of MAGICC/SCENGEN

MAGICC/SCENGEN provides an accessible, low cost and versatile tool for generating regional climate scenarios for anywhere in the world. It draws upon the results of more complex models and extensive climate data sets, generates results that are consistent with the IPCC Second Assessment Report, and allows users to explore and quantify different aspects of uncertainty with regard to future climate. There are, nevertheless, a number of concerns that have been expressed about the limitations of SCENGEN in particular. The most frequently cited ones are:

- its reliance on pattern-scaling methods to combine GCM results with MAGICC;
- the absence of any sophisticated downscaling techniques;
- the restricted coverage of the 0.5º observed climate data set (only four large regions at this resolution);
- the lack of any consideration of inter-annual climate variability.

The latter two concerns will be addressed in subsequent versions of SCENGEN (see below), but it is worth making one or two comments about the first two concerns.

Pattern-scaling

A brief explanation of the pattern-scaling method employed in SCENGEN has been provided in Box 2.4 (p.15). Pattern-scaling is a pragmatic solution to two problems, namely: a) it is not feasible to undertake a new GCM experiment for every possible combination of emissions scenario and climate sensitivity; and b) even if it were, it would still not be possible to include all of the results from such experiments in a versatile, portable and manageable software package. While pattern-scaling does have its limitations, most notably its reliance on the assumption of linearity between global and regional climate responses, a better solution to the above two problems has not yet been found. Pattern-scaling methods have been comprehensively investigated in the recent paper by Mitchell *et al.* (1999) and they are also assessed in Chapter 13 of Working Group I of the forthcoming IPCC Third Assessment Report (Mearns *et al.*, 2001).

The need for downscaling

A brief discussion of the issues involved in downscaling is provided on p.37 of this Workbook. SCENGEN adopts a very simple approach to the problem by combining GCM-resolution climate change data (e.g. at 5º latitude/longitude resolution) with observed climate data provided at finer (0.5º) resolution. The same simple additive approach to downscaling can also be used outside SCENGEN by combining the changes in mean monthly climate obtained from SCENGEN for a given GCM grid box with observed monthly station data (either means or time series) for locations within that same GCM grid box. An illustration of this approach is provided on p.37. For many climate scenario applications these simple approaches are quite satisfactory to allow the first-order assessment of regional or national climate change impacts.

There are, of course, more sophisticated downscaling techniques available, none of which, however, can be included in climate scenario generators such as MAGICC/SCENGEN. The full range of these techniques[27] is assessed in Chapter 10 of Working Group I of the forthcoming IPCC Third Assessment Report (Giorgi *et al.*, 2001). The two most commonly used techniques are statistical downscaling and dynamical downscaling. Some aspects of statistical downscaling have already been noted (p.37; and are reviewed in Wilby and Wigley, 1997). It is worthwhile here to add to this by considering dynamical downscaling (i.e., the use of Regional Climate Models - RCMs) further. Do RCMs provide a practical solution for high resolution climate scenario needs in the current round of V&A assessments?

There are several acknowledged limitations to the regional climate modelling approach:

- Just because results from RCM experiments show greater spatial detail than GCMs, including the appearance of sensitivity to more realistic geography, does not automatically qualify their results as more "accurate". The most important limitation is that the RCM is completely dependent upon the boundary conditions extracted from the GCM experiments used to drive the regional atmosphere. Scenarios derived from RCM experiments therefore depend greatly on the validity of the driving GCM.
- It is also worth noting that RCM output even at 50km resolution is still not adequate for some impact assessments. In cases such as a small river catchment or the simulation of agriculture or land use at 1 km or 10 km scales there will still be a need for some other form of downscaling.
- RCMs require considerable computing resources, are as expensive to run as a GCM, and require considerable technical expertise to implement and interpret.
- At the current time very few climate change experiments with simulation periods longer than 10 years have been performed using RCMs, and those that have are generally for regions such as Europe, North America and Australia. Short simulations of 10 years or less are not adequate for identifying robust anthropogenic climate change signals at regional scales.

RCMs nevertheless hold much promise in the future for providing higher resolution climate scenarios at the regional scale. These will not be achieved cheaply or easily, however, and will require well-organised programmes of scientific training, collaboration and inter-comparison. Furthermore, the validity of RCM-based scenarios will always remain subject to the validity of the parent GCM. For a good few years to come there will also be a role for more versatile CSGs such as MAGICC/SCENGEN.

Future Developments of MAGICC and SCENGEN

Further developments of MAGICC and SCENGEN are planned. For example, following the publication of the IPCC Third Assessment Report in spring 2001, a new version of MAGICC (Version 3) will be designed. This new version of MAGICC will reproduce the results reported in the IPCC Third Assessment Report, taking into account new understanding about gas cycles, about concentration-forcing relationships, and about the climate sensitivity. It will also include the full set of the approved SRES emissions scenarios.

Two major enhancements to SCENGEN are also envisaged. First is the inclusion of the observed 1961-90 mean monthly climate data set at 0.5º resolution for all global land areas (Version 2.4 only has these data for four sub-continental regions). A new 10' gridded land climate data set for 1961-90 currently being constructed by the Climatic Research Unit at the University of East Anglia, Norwich, may also be employed. This would represent a nine-fold increase in spatial resolution over the 0.5º resolution data set. Second will be the ability in SCENGEN Version 3 to present future changes in inter-annual climate variability. This contrasts with Version 2.4 which can represent changes only in 30-year average climate.

Consideration is also being given to the development of an integrated training package for climate scenario construction and application. Such a training package would be developed in conjunction with the NCSP/GEF office in New York and maybe the IPCC TGCIA. It would be built around Versions 2.4 or 3 of MAGICC/SCENGEN, but would encompass wider issues in climate scenario design, including the role of RCMs, weather generators and other downscaling techniques.

[27] In the IPCC Third Assessment Report, these are referred to as regionalisation techniques.

ANNEX A: REFERENCES AND FURTHER READING

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ANNEX B: THE HISTORY OF MAGICC AND SCENGEN

MAGICC

MAGICC has been developed in the Climatic Research Unit since the late 1980s, mainly by Professor Tom Wigley and Dr Sarah Raper. The forerunner of MAGICC was STUGE, and an early version of the model was used in the ESCAPE integrated climate change assessment model under the name of STAGGER. MAGICC (Version 2.3) has been used extensively by the IPCC in its Second Assessment Report and a new Version of MAGICC (3.0) will be released later in 2001 after the IPCC Third Assessment Report has been published. A Technical Manual for MAGICC/SCENGEN Version 2.4 has been published to coincide with this Workbook and will be available from http://www.cru.uea.ac.uk/~mikeh/software/magicc.htm as:

Wigley,T.M.L., Raper,S.C.B., Hulme,M. and Smith,S. (2000) *The MAGICC/SCENGEN Climate Scenario Generator: Version 2.4, Technical Manual*, Climatic Research Unit, UEA, Norwich, UK, 48pp.

Credits:
Concepts: Tom Wigley, Tom Holt and Sarah Raper
Programming: Tom Wigley, Sarah Raper and Mike Salmon.
Gas Cycle Models: Tom Wigley and Tom Osborn
Gas Files: Tom Wigley and Steve Smith
Graphical User Interface Design: Mike Salmon, Tom Wigley, Tom Holt.
Graphical User Interface Programming: Mike Salmon.

SCENGEN

SCENGEN has been developed in the Climatic Research Unit since the early 1990s, mainly by Professor Tom Wigley and Dr Mike Hulme. The forerunner of SCENGEN was CLIMAPS, which was used in the ESCAPE integrated climate change assessment model. Version 2.4 of SCENGEN has an updated set of GCM patterns available and, compared to earlier public release versions, has implemented the function for combining GHG and aerosol patterns of change. Version 2.4 also contains observed 1961-90 global climate data fields at 5º resolution from the New *et al*. (1999) climate data set. A Technical Manual for MAGICC/SCENGEN has been published to coincide with this Workbook and will be available from http://www.cru.uea.ac.uk/~mikeh/software/magicc.htm as:

Wigley,T.M.L., Raper,S.C.B., Hulme,M. and Smith,S. (2000) *The MAGICC/SCENGEN Climate Scenario Generator: Version 2.4, Technical Manual*, Climatic Research Unit, UEA, Norwich, UK, 48pp.

Credits:
Concepts: Tom Wigley, Ben Santer and Mike Hulme
Programming: Tom Wigley, Sarah Raper and Mike Salmon.
Data Sets: Mike Hulme, Olga Brown, Martin Crossley, Tao Jiang and Mark New
Graphical User Interface Design: Tom Wigley, Mike Hulme and Olga Brown
Graphical User Interface Programming: Olga Brown and Mike Salmon.

ANNEX C: SOME RELEVANT WEB SITES

Guidelines on the use of scenario data for climate impact and adaptation assessment:

Version 1 IPCC Task Group on Scenarios for Climate Impact Assessment:
http://ipcc-ddc.cru.uea.ac.uk/cru_data/support/guidelines.html

Intergovernmental Panel on Climate Change:
http://www.ipcc.ch/

IPCC Data Distribution Centre: http://ipcc-ddc.cru.uea.ac.uk/

National Communications Support Programme (UNDP/GEF): http://www.undp.org/cc/

Special Report on Emissions Scenarios (SRES):
http://sres.ciesin.org

UN Framework Convention on Climate Change:
http://www.unfccc.de/

Three other Climate Scenario Generators

Each of these generators uses a similar approach to MAGICC/SCENGEN, but has been developed for different regions. COSMIC allows country-average statistics to be generated; OZCLIM and the CLIMPACTS family include a number of impact models within the framework.

COSMIC:
http://crga.atmos.uiuc.edu/COSMIC/index.html
The COSMIC model provides climate-change impact modellers and policy analysts a flexible system that can produce a full range of dynamic country-specific climate change scenarios. One goal of COSMIC is to expand the use of integrated assessment modelling for addressing the potential impacts of climate change in a way that better reflects the experiences of researchers from developing countries. These researchers (and others at universities around the world) may not have access to state-of-the-art transient GCM simulations. The expense of running these supercomputer models limits their availability and ease of use. The COSMIC model helps remove this limitation. COSMIC can provide easy access to credible climate-change scenarios that are consistent with the state-of-the-art, fully coupled, transient ocean-atmosphere GCM simulations.

OZCLIM: http://www.dar.csiro.au/res/cm/ozclim.htm
OzClim is a software package that generates climate change scenarios for Australia and simulates potential climate change impacts for Australia. It is a Windows 95-based application that can be adapted to incorporate a wide range of climatic variables and impact models. The CSIRO Division of Atmospheric Research is inviting potential collaborators to continue the development of OzClim by contributing their expertise in all areas of climate impacts research.

The *CLIMPACTS* family of generators:
http://www.waikato.ac.nz/igci/climpacts_webpage/
The CLIMPACTS system is an integrated computer-based model developed to examine the sensitivity of New Zealand's climate, agricultural and horticultural sectors to climate change and variability. At the top end of the system is MAGICC (Version 2.3). The global temperature changes from MAGICC are used to scale patterns of climate change for New Zealand, derived from more complex GCMs. The scaled patterns of climate change are then used to perturb the reference (1951-80) climate for New Zealand, to give scenarios of future climate up to 2100. This climate scenario generator is linked to a range of crop models, as well as an extreme event analysis tool. It is thus possible, using the CLIMPACTS system, to ask a wide range of policy-relevant questions, in particular relating to changes in areas of crop suitability and changes in climate-related risk. Other derivatives of CLIMPACTS include VANDACLIM, PACCLIM, BDCLIM and FIJICLIM.

ANNEX D: SOME PUBLIC INTERNET SOURCES OF OBSERVED CLIMATE DATA

The most authoritative and comprehensive source of observed climate data for a given country study will almost invariably be the respective National Meteorological and / or Hydrometeorological Agency (NMA). It is these Agencies which are responsible for the measurement, quality control and collation of meteorological and climate data in a given country. The vast majority of climate data that end up in global archives and data sets originate from NMAs. It is sometimes, however, neither easy nor cheap to obtain data from such sources - it depends very much on the pricing policy of the NMA and on the relationship the study team have with the NMA. Given that the V&A assessments being performed for the UNFCCC are government-led activities, and that NMAs are usually an arm of government, some arrangement for V&A assessments to use NMA data should normally be worked out.

If this is not the case then study teams are directed to some international, public domain data sets, a few of which are listed below. These sites contain a variety of observed station and gridded data at a variety of spatial resolutions. It is unlikely, however, that these data sources will provide the richness of observed climate data that could in principle be obtained through a NMA.

Carbon Dioxide Information and Analysis Centre:
http://cdiac.esd.ornl.gov/

Climatic Research Unit, UEA, Norwich:
http://www.cru.uea.ac.uk/

El Nino / Southern Oscillation:
http://www.ogp.noaa.gov/enso/

Global Historic Climatology Network:
http://www.ncdc.noaa.gov/ol/climate/research/ghcn/ghcn.html

Global Precipitation Climatology Centre:
http://www.dwd.de/research/gpcc/

IGBP Data Information System:
http://www.igbp.kva.se/dis1.html

International Research Institute for Climate Prediction:
http://iri.ldeo.columbia.edu/

IPCC Data Distribution Centre:
http://ipcc-ddc.cru.uea.ac.uk/

LARS Weather Generator:
http://www.lars.bbsrc.ac.uk/model/larswg.html

National Climate Data Support Centre:
http://www.ncdc.noaa.gov/

NCAR Data Support Centre:
http://www.scd.ucar.edu/dss/

ANNEX E: SAMPLE OUTPUT FROM A MAGICC REPORT FILE

```
NSIM =  1 : DELT(2XCO2) = 1.500DEGC
FULL GLOBAL SO2 EMISSIONS

VARIABLE W : NH W = ZERO WHEN OCEAN TEMP =  7.0
VARIABLE W : SH W = ZERO WHEN OCEAN TEMP =  7.0
XKNS= 1.0 : XKLO= 1.0
HM= 90.0M : XK=1.0000CM**2/SEC
PI= .2000 : INITIAL W= 4.00M/YR
GSIC MODEL PARAMS : DTSTAR =  .900 : DTEND = 4.500 : TAU  = 150.0 : INIT VOL =  30.0
GREENLAND PARAMS  : BETA   =  .010
ANTARCTIC PARAMS  : BETA1  = -.045 : BETA2=  .000 : DB3   = -.040

DIFF/L SENSITIVITY CASE : RLO = 1.300 : XLAML =    1.7885 : XLAMO =    3.5824

1880-1990 CHANGES : GLOBAL DTEMP =   .204 :   DMSL =  -.963
DTNHL =   .142 : DTNHO =   .232 :  DTSHL =   .129 :   DTSHO =   .236
DTNH =   .194 :  DTSH =   .214 : DTLAND =   .138 : DTOCEAN =   .235

 ** TEMPERATURE AND SEA LEVEL CHANGES FROM 1976 **
      (FIRST LINE GIVES 1765-1990 CHANGES : ALL VALUES ARE MID-YEAR TO MID-YEAR)

 DT2X = 1.50 : VARIABLE W

 LOW CLIMATE AND SEA LEVEL MODEL PARAMETERS
 DEFAULT GAS CYCLE MODEL PARAMETERS
```

YEAR	DELTAQ	TEMP	TL/TO	MSLTOT	EXPN	GLAC	GREENL	ANTAR	WNH	YEAR
TO1990	1.312	.2877	.706	.10	4.19	.45	.08	-4.63	3.82	
1990	.431	.1100	.706	.45	.90	.17	.03	-.65	3.82	1990
1995	.619	.1564	.792	.73	1.32	.26	.05	-.90	3.79	1995
2000	.822	.2070	.863	1.08	1.80	.38	.07	-1.16	3.77	2000
2005	1.000	.2513	.872	1.49	2.32	.51	.09	-1.44	3.74	2005
2010	1.185	.2964	.876	1.95	2.88	.67	.12	-1.72	3.72	2010
2015	1.376	.3436	.881	2.46	3.49	.84	.15	-2.01	3.69	2015
2020	1.551	.3876	.869	3.02	4.13	1.02	.19	-2.32	3.66	2020
2025	1.723	.4307	.856	3.62	4.80	1.22	.22	-2.63	3.64	2025
2030	1.916	.4799	.866	4.26	5.51	1.44	.26	-2.95	3.61	2030
2035	2.106	.5301	.875	4.95	6.26	1.67	.31	-3.29	3.58	2035
2040	2.287	.5794	.880	5.67	7.04	1.92	.36	-3.63	3.56	2040
2045	2.454	.6265	.884	6.43	7.83	2.18	.41	-3.99	3.53	2045
2050	2.617	.6717	.886	7.21	8.65	2.45	.47	-4.36	3.50	2050
2055	2.809	.7264	.915	8.02	9.49	2.74	.53	-4.74	3.48	2055
2060	2.982	.7797	.940	8.87	10.35	3.05	.59	-5.13	3.45	2060
2065	3.137	.8293	.959	9.72	11.23	3.37	.66	-5.53	3.42	2065
2070	3.276	.8750	.975	10.59	12.11	3.70	.73	-5.94	3.40	2070
2075	3.400	.9171	.988	11.46	12.98	4.04	.80	-6.37	3.38	2075
2080	3.517	.9570	1.001	12.33	13.86	4.39	.88	-6.80	3.36	2080
2085	3.623	.9944	1.012	13.19	14.73	4.74	.96	-7.24	3.34	2085
2090	3.720	1.0289	1.021	14.04	15.59	5.10	1.04	-7.69	3.32	2090
2095	3.807	1.0609	1.030	14.89	16.44	5.46	1.13	-8.14	3.30	2095
2100	3.887	1.0907	1.037	15.72	17.29	5.83	1.22	-8.61	3.29	2100
YEAR	DELTAQ	TEMP	TL/TO	MSLTOT	EXPN	GLAC	GREENL	ANTAR	WNH	YEAR

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Technical Information for Using MAGICC/SCENGEN

The Climatic Research Unit have produced a CD-ROM containing MAGICC/SCENGEN (Version 2.4, February 2000) for Windows 95/98/NT. The minimum requirement is a desktop PC with a Pentium processor and 32MB RAM (64MB recommended). 300MB of free disk space is recommended. The print driver supplied with the software is for a Hewlett Packard PaintJet printer (a limited range of other printers may be supported). However, images from MAGICC/SCENGEN can be saved as encapsulated postscript and/or ASCII files and imported into other software and then printed on a range of printers.

Loading

Place the CD-ROM in your CD drive. Using *My Computer* click on the CD drive (usually D). This will show you the top-level files on the CD. There is a "Readme.txt" file that you should examine. To install the software click on the "Setup.bat" file. This will take you into DOS and an installation batch file will execute automatically. After MAGICC has loaded, you will be asked whether you also want SCENGEN loaded (note: you need 300MB of disk space for SCENGEN). Separate MAGICC and SCENGEN directories will be created in your top-level on disk C. To uninstall MAGICC/SCENGEN, simply delete these /magicc and /scengen directories. **Important Note for NT users:** under NT, the MAGICC gas files (containing the emissions scenarios) are not recognised owing to the uppercase initial in the gas filenames. To correct this you will need to manually alter all the 19 gas filenames in the /magicc directory, converting the uppercase initial letter into a lower case letter.

Running

With your software loaded, you can enter the software by moving to Programs and then finding and clicking the MAGICC icon. From within MAGICC you can access SCENGEN as necessary. Both MAGICC and SCENGEN have fully operational help menus, including some General Information, which should help you navigate your way around the software.

Licencing

MAGICC/SCENGEN 2.4 is supplied ***only on the condition*** that you read, sign, copy and return the relevant Licence Agreement. You ***must*** abide by this Agreement which, among other things, forbids transfer (whether or not for sale) to a Third Party without permission from the developer. You will also find copies of the Licence Agreement in the top level /magicc directory, supplied as Word, txt and pdf files. ***Please print a copy of this Agreement, and then read, sign, copy and return to the named administrator.*** You then become an authorised user of the software.

Technical questions about the loading and running of MAGICC/SCENGEN should be directed to Mike Salmon (email: m.salmon@uea.ac.uk).