GUIDELINES ON THE USE OF SCENARIO DATA FOR CLIMATE IMPACT AND ADAPTATION ASSESSMENT

Version 1

December 1999

Task Group on Scenarios for Climate Impact Assessment

Intergovernmental Panel on Climate Change

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1 INTRODUCTION

1.1 Background

In 1995, the Intergovernmental Panel on Climate Change (IPCC) finalised a major international scientific review of climate change - the Second Assessment Report (SAR). It comprised three volumes prepared, respectively, by Working Groups I, II and III of the IPCC, on the science of climate change (IPCC, 1996a), impacts, adaptation and mitigation of climate change (IPCC, 1996b) and the economic and social dimensions of climate change (IPCC, 1996c).

One of the conclusions of the volume on impacts, prepared by Working Group II, was that "Impacts are difficult to quantify, and existing studies are limited in scope" (IPCC, 1996b, p. 24). The editors continue: "Most impact studies have assessed how systems would respond to climate change resulting from an arbitrary doubling of equivalent carbon dioxide (CO_2) concentrations. Furthermore, very few studies have considered dynamic responses to steadily increasing concentrations of greenhouse gases; fewer still have examined the consequences of increases beyond a doubling of equivalent atmospheric CO_2 concentrations, or assessed the implications of multiple stress factors." These comments reflect a time lag and inconsistency problem that has characterised the IPCC review process since its inception in 1988. The problem is illustrated schematically in Table 1.1.

At the core of the problem is the structure of the IPCC review itself, in which the three volumes are prepared in parallel. This has resulted in a mismatch of information and assumptions between the Working Groups. Thus, while Working Group I reviewed the most recent published projections of future climate change, based on transient coupled ocean-atmosphere general circulation model (AOGCM) simulations, these results were not available to the impacts community in preparing their assessments, which were simultaneously reviewed by Working Group II. Instead, most of these impact studies relied on climate projections from earlier, more rudimentary GCMs, often comprising equilibrium 2 x CO_2 simulations which were published some 5-10 years previously.

Similarly, the simplified assumptions used in climate model simulations about the radiative forcing of the climate due to changing greenhouse gas and aerosol concentrations (for example, an increase of 1% per year in compounded carbon dioxide concentration is commonly assumed) represent only a limited subset of the plausible atmospheric conditions under a range of emissions scenarios* reviewed by Working Group III. However, the computational expense of running GCMs precludes multiple simulations for alternative scenarios of radiative forcing, so the implications for climate of new emissions scenarios usually have to be interpreted in the light of pre-existing GCM projections, rather than undertaking new model runs.

Furthermore, in addition to the vintage of climate projections adopted by impact assessors, another difficulty faced by reviewers in attempting to summarise and synthesise the results of impact studies for the Second Assessment Report was a lack of consistency in projections. Different climate projections were adopted in different studies, in different regions (or within the same region), and in different sectors. Moreover, even where the same climate projections were assumed, these might not be applied in the same way in different impact studies. Finally,

* The terms scenario and projection are used interchangeably in this report to indicate "a coherent, internally consistent and plausible description of a possible future state of the world" (IPCC, 1994).

studies were also inconsistent in their methods of projecting changes in climate alongside concurrent changes in related socio-economic and environmental conditions.

Table 1.1 Approximate chronology of the IPCC process in relation to general circulation model (GCM) simulations, their adoption in impact studies and the development of IPCC emissions scenarios.

Date	**IPCC process**	**GCM simulations**	**GCM-based scenarios used in impact studies**	**IPCC emissions scenarios**
1980-1987	-	Equilibrium low resolution AGCM	-	-
1988-1990	First Assessment Report (FAR) 1990	Equilibrium high resolution AGCM	Equilibrium low 2 x CO_2	Scenarios A-D (A = BaU)
1991-1992	FAR Supplement 1992	Transient AOGCM cold start GHG-only (Scenario A emissions)	Equilibrium low 2 x CO_2	IS92a-f
1993-1996	Second Assessment Report 1996	Transient AOGCM warm-start GHG + aerosol (0.5 or 1% /year emissions) Ensembles Multi-century control	Equilibrium low/high Transient cold-start	IS92a-f (modified)
1997-1998	Regional Impacts 1998	Transient AOGCM Ensembles Multi-century control	Equilibrium low/high Transient cold-start/warm-start	IS92a-f (modified)
1999-2001	*Third Assessment Report 2001*	*Transient AOGCM Ensembles Multi-century control SRES-forced? Stabilization*	*Equilibrium low/high Transient cold-start/warm-start Multi-century control Ensembles*	*SRES*

Recognising these weaknesses, and mindful of forthcoming preparations for the Third Assessment Report, due to be completed in 2001, the IPCC organised a Workshop on Regional Climate Change Projections for Impact Assessment in September 1996 in London. The main outcome of the Workshop was the formation of an IPCC Task Group on Scenarios for Climate Impact Assessment (TGCIA) whose role is to consider the strategy for the provision of regional climate change information with particular focus on the IPCC Third Assessment Report, and on capacity building for future IPCC assessments (see Appendix 1).

These Guidelines represent part of an initiative by the Task Group to improve consistency in the selection and application of scenarios in climate impact and adaptation assessments and, in so doing, to reduce the time lag of information exchange between the different scientific communities. They offer guidance on the interpretation and application of scenario data in impact and adaptation assessment. They also provide user support for the IPCC Data Distribution Centre, which has been established under the direction of the Task Group, to make freely available a number of recent global data sets of baseline and scenario information on climatic, environmental and socio-economic conditions.

This is the first version of the Guidelines. It is our intention to revise the document on a regular basis to provide updates on available scenario information and to accommodate feedback from users.

1.2 The IPCC Data Distribution Centre (DDC)

The IPCC Data Distribution Centre (DDC) was established in 1998, following a recommendation by the TGCIA, to facilitate the timely distribution of a consistent set of up-to-date scenarios of changes in climate and related environmental and socio-economic factors for use in climate impact and adaptation assessment. While impact researchers are free to use whatever simulations are appropriate for their studies, it is hoped that the wide accessibility to these recent scenarios, and the knowledge that other research groups are probably doing likewise, may persuade analysts to adopt some or all of the scenarios held in the DDC. One of the clear objectives of the Centre is that new assessments making use of these scenarios can feed into the review process of the IPCC, in particular to the Third Assessment Report (TAR).

Data are being provided by the DDC over the World Wide Web and on CD-ROM. All research groups supplying data sets have agreed to these being in the public domain. The data are provided free of charge, but all users are requested to register to ensure both that the data are used for public scientific research rather than for commercial applications and also that they can be informed of possible modifications, additions and other new developments at the DDC.

The DDC is a shared operation between the Climatic Research Unit (CRU) in the United Kingdom and the Deutsches Klimarechenzentrum (DKRZ) in Germany. In addition, several regional centres have agreed to serve as mirror sites for the data archive, as well as offering specialised regional user support on top of the basic DDC functions. Technical inputs from other centres or organisations with experience in the preparation and distribution of climate scenarios have also been solicited, especially in the preparation of these Guidelines.

The DDC provides three types of data or information, which meet certain criteria laid down by the TGCIA. They are introduced briefly here and described in more detail in subsequent sections of these Guidelines:

1. <u>Observed global climate data sets</u>. These include a gridded terrestrial climatology of 1961-1990 mean monthly data for nine variables on a 0.5º latitude/longitude grid, together with decadal anomalies from this mean for the period 1901-1995. Pointers are also provided to other relevant global climatologies.

2. <u>Non-climatic baseline and scenario information</u>. The baseline data include a set of country and regional-level indicators of socio-economic and resource variables as estimated at the beginning of the 1990s. The scenario data supplied are based on the assumptions underlying the six emissions scenarios prepared by the IPCC in 1992 (the IS92 scenarios - Leggett *et al.*, 1992) and a new set of preliminary, unapproved emissions scenarios developed for the forthcoming IPCC Special Report on Emissions Scenarios (SRES scenarios).

3. <u>Results from global climate model experiments</u>. Monthly averaged results from climate change simulations performed by a number of climate modelling centres are being made available. The results have been extracted from transient, warm-start AOGCM simulations

which include both greenhouse gas only and greenhouse gas and sulphate aerosol forcings. Results from control simulations, ensembles and time-slice experiments are also being provided, where possible, as well as consistent scenarios of global sea-level change and CO_2 concentrations. Explanations of these model simulations are provided later in this document.

1.3 Structure and objectives of these Guidelines

The Guidelines have four main objectives:

1. To introduce and describe the information and analytical tools being provided by the Data Distribution Centre

2. To offer guidance on how to interpret the baseline and scenario data held by the DDC and elsewhere, in order to facilitate the informed selection and use of data in impact and adaptation assessments

3. To highlight and illustrate the key steps and procedures that are commonly required in applying baseline and scenario data in impact and adaptation assessments

4. To suggest standards for reporting the results of impact and adaptation studies.

In 1994, the IPCC published *Technical Guidelines on Assessing Climate Change Impacts and Adaptations* (IPCC, 1994) which presented a framework for conducting impact assessments that comprised seven steps (Figure 1.1). The selection and application of baseline and scenario data, the main focus here, are largely dealt with in steps 3-6 of this framework. Similar frameworks have been adopted in various country study programmes (e.g. Smith *et al*., 1996; Smith and Hulme, 1998) for which corresponding analytical steps can be identified. The use of baseline and scenario data also figure prominently in other, alternative methodological frameworks for climate change vulnerability and adaptation assessment, for example, the *IPCC Common Methodology* for assessing coastal zone vulnerability to sea-level rise (WCC'93, 1994).

The present Guidelines are divided into sections that mirror, approximately, the chronological order in which baseline data and scenarios are commonly introduced and applied in the majority of these assessments. First the present-day situation is described, requiring recent average baseline data and information on variability and extremes that are vital for understanding the vulnerability and adaptability of a given exposure unit[*]. Second, a core set of climatic and non-climatic scenarios are selected and interpreted for the region and exposure unit under study. Third, methods are described for examining the sensitivity of the exposure unit across a plausible range of climate and non-climatic changes, and for applying the core set of scenarios. Finally, some minimum reporting standards are outlined for the acknowledgement of data sources and presentation of results.

[*] An exposure unit is an activity, group, region or resource exposed to significant climatic variations (IPCC, 1994).

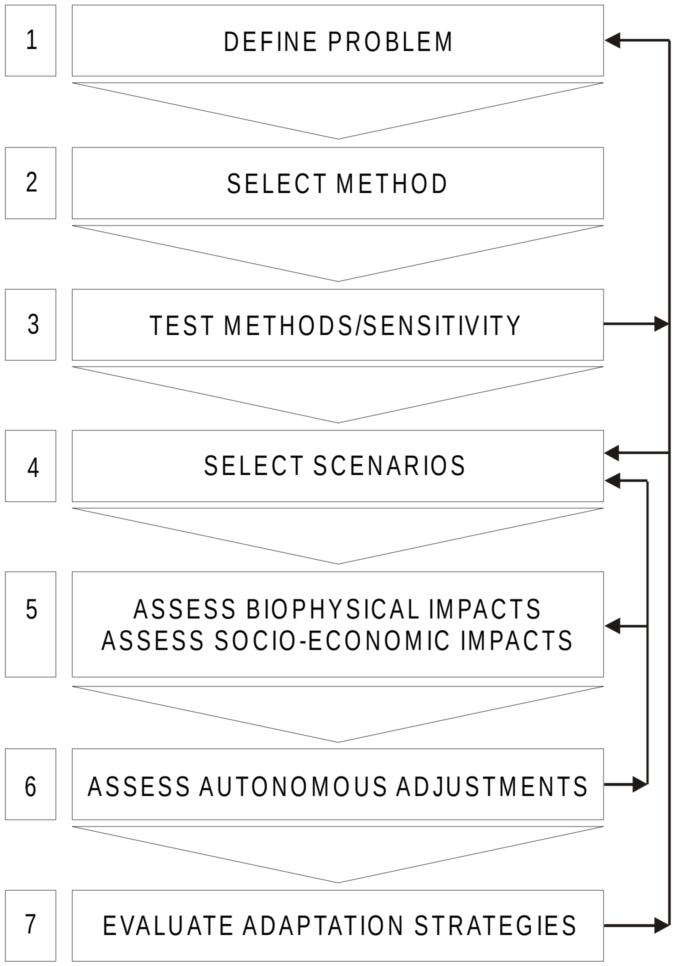


Figure 1.1 A seven step framework for climate impact assessment (IPCC, 1994)

2 SPECIFYING THE BASELINE

In order to assess the implications of future changes in the environment, society and economy on an exposure unit, it is first necessary to have information about the present-day or recent conditions as a reference point or baseline. Baseline information is important for:

- characterising the prevailing conditions under which an exposure unit functions and to which it must adapt
- describing average conditions, spatial and temporal variability and anomalous events, some of which can cause significant impacts
- calibrating and testing impact models across the current range of variability
- identifying possible ongoing trends or cycles
- specifying the reference situation with which to compare future changes

In this section, these different functions of the baseline are discussed under two headings: the climatological baseline and non-climatic baselines. These baselines are sometimes collectively referred to as the "current baseline", to distinguish them from the "future baseline", a term that has been used to describe future changes in environmental and socio-economic conditions that will occur regardless of climate change. Since the future baseline is based on projections, for the purposes of this report it is considered under scenarios in section 4.

2.1 The climatological baseline

In order to characterise the present-day climate in a region, good quality observed climatological data are required for a given baseline period. Issues to consider in selecting the climatological baseline include the types of data required, duration of the baseline period, sources of the data and how they can be applied in an impact assessment.

2.1.1 Data needs of the impact community

The baseline climatological information required by impact analysts varies enormously from study to study. Some options include:

- <u>Variables:</u> The most common variables applied in impact studies are surface (screen height) observations of air temperature and precipitation. However, many impact models require a larger set of surface variables as input, for example, solar radiation, humidity, wind speed, soil temperature and snow cover. In addition, for certain scenario construction procedures (e.g. statistical downscaling from GCM outputs), daily upper air data, mean sea-level pressure or circulation indices may also be needed. Derived variables, such as accumulated temperature, evapotranspiration and runoff, are rarely required in impact studies, as these are usually computed directly from primary observations. However, some indices may be useful for identifying important large scale climatic variations, including the Southern Oscillation Index (related to El Niño/La Niña events), the North Atlantic Oscillation (associated with mid-latitude atmospheric circulation), the strength of the Asian monsoon, and indices of large volcanic eruptions and solar activity.
- <u>Spatial scale:</u> Data requirements may be for a single site (e.g. for testing complex impact models such as crop climate models), a region (e.g. a dense network of sites over a river catchment) or the whole globe (e.g. for modelling human disease risk using interpolated data over a grid).
- <u>Temporal resolution:</u> This may range from annual through seasonal and monthly means to daily or sub-daily time steps. In some cases long-term averages may suffice (e.g. for

mapping vegetation distribution) but in others annual time series are essential (e.g. for computing peak demand for space heating or cooling). Finally, studies of disasters often require knowledge of the distribution of extremes in certain time windows (e.g. for computing the risk of storm surges).

Summary - data needs: *The spectra of requirements for data for impact studies range from single variable to comprehensive, from local to extensive and from sub-daily to multi-decadal or century-scale.*

2.1.2 Baseline period

The baseline period is usually selected according to the following criteria (IPCC, 1994):

- representative of the present-day or recent average climate in the study region;
- of a sufficient duration to encompass a range of climatic variations, including a number of significant weather anomalies (e.g. severe droughts or cool seasons);
- covering a period for which data on all major climatological variables are abundant, adequately distributed over space and readily available;
- including data of sufficiently high quality for use in evaluating impacts;
- consistent or readily comparable with baseline climatologies used in other impact assessments.

A popular climatological baseline period is a 30-year "normal" period as defined by the World Meteorological Organisation (WMO). The current WMO normal period is 1961-1990. As well as providing a standard reference to ensure comparability between impact studies, other advantages of using this baseline period include:

- The period ends in 1990, which is the common reference year used for climatic and non-climatic projections by the IPCC in the First and Second Assessment Reports (and retained for the Third Assessment Report).
- It represents the recent climate, to which many present-day human or natural systems are likely to have become reasonably well adapted (though there are exceptions, such as vegetation zones or groundwater levels, that can have a response lag of many decades or more relative to the ambient climate).
- In most countries, the observed climatological data are most readily available for this period, especially in computer-coded form at a daily time resolution.

Nevertheless, in selected cases there may be difficulties with adopting this baseline period, including:

- In some countries there is better access to data from an earlier period (e.g. 1951-1980 or 1931-1960).
- In some, though not all, regions more recent periods may already contain a significant warming trend which may be greenhouse gas related. Globally, the 10 warmest years in the 144-year record have occurred between 1983 and 1999. Moreover, recent years have also been characterised by a high frequency of El Niño events, some of them very strong.
- Climatological data from the 1990s will certainly be required for the calibration and testing of many impact models. Moreover, 1961-1990 will be superseded by 1971-2000 as a new standard 30-year averaging period shortly before the publication of the Third Assessment Report. However, it will take between 1 and 5 years for these normals to become widely available worldwide.
- A 30-year period may not be of sufficient duration to reflect natural climatic variability on a multidecadal timescale, which could be important in considering long-term impacts.

Summary - climatological baseline period: *If possible, for the purposes of consistency, 1961-1990 should be adopted as the climatological baseline period in impact and adaptation assessments. However, if an alternative period is adopted, researchers are encouraged to compare the regional climatic characteristics of this period with those of 1961-1990, for example using the global observed terrestrial climatology provided by the Data Distribution Centre.*

2.1.3 Obtaining baseline climatological data

There are a number of alternative sources of baseline climatological data that can be applied in impact assessments. These are not mutually exclusive, and include:

- National meteorological agencies and archives
- Supranational and global data sets
- Climate model outputs
- Weather generators

2.1.3.1 National meteorological agencies and archives

The most common source of observed climatological data applied in impact assessments is the national meteorological agencies. It is these agencies that usually have responsibility for the day-to-day operation and maintenance of national meteorological observational networks for purposes of weather forecasting and other public services. They are also relied upon to transmit surface and upper air observations from key "synoptic" sites in real time over the global telecommunications system for use in numerical weather prediction models. It is usual for these observations, along with data from other climatological and hydrological stations, to be processed and stored in archives by the responsible agency. Many agencies also routinely interpolate station data onto a regular grid, for a range of spatial applications.

In many cases, summary statistics are published in yearbooks or as climatological normals (for 30-year periods), although there can be time lags of several months or years between observations being collated, quality controlled, analysed and published. However, most data used in impact assessments nowadays are required in digital form. These data can usually be obtained by potential users, but under a variety of terms (including cost) that are highly country and case specific. To illustrate the great diversity of data availability, in a survey of 39 national meteorological agencies in Europe, the cost of obtaining a comparable set of 30-year mean monthly climatological normals varied from no charge to as much as 297 US$ per variable per station (Hulme, 1994).

Data are commonly available from national agencies at time resolutions ranging from hourly to monthly, and while adequate monthly data can frequently be obtained from global or regional data sets (see below) station data at a daily resolution or higher are usually obtained from national sources.

2.1.3.2 Supranational and global data sets

As well as serving national needs, climatological data from different countries have also been combined into various supranational and global data sets. These have been developed to serve various needs, including:

- Monitoring of observed variations in global and regional climate and detection of anthropogenically-induced climate change
- Testing and development of numerical weather prediction models
- Validation of global climate models, to compare simulated with observed climate
- Regional and global-scale climate impact assessments, as inputs to impact models

The data sets include observations of surface variables at a monthly time step over land and ocean, surface and upper air observations at a daily time step from sites across certain regions and, for recent decades, satellite observations. Many of these data sets are available as mean values, for various periods, often interpolated to a regular grid. However, with improved processing and storage capacity, there are now a number of historical data sets providing annual time series of gridded or site observations.

A selection of data sets that are available in the public domain (e.g. through the Internet) are listed in Table 2.1. One of these, the CRU Global Climate Data Set, is being made directly available for use from the Data Distribution Centre (see below).

2.1.3.3 Climate model outputs

There are two types of information from global climate models that may also be useful in describing the climatological baseline: reanalysis data and outputs from GCM control simulations.

Reanalysis data**:** These are fine resolution gridded data which combine observations with simulated data from numerical models. Through a process known as data assimilation, the observations (available only sparsely and irregularly over the globe), along with data from satellites and information from a previous model forecast, are input into a short-range weather forecast model. This is integrated forward by one time step (typically 6 hours) and combined with observational data for the corresponding period. The result is a comprehensive and dynamically consistent three-dimensional gridded data set (the "analysis") which represents the best estimate of the state of the atmosphere at that time. The assimilation process fills data voids with model predictions and provides a suite of constrained estimates of unobserved quantities such as vertical motion, radiative fluxes, and precipitation.

Large quantities of past observational data that were used operationally as inputs to earlier versions of weather forecasting models have subsequently been "reanalysed" using the current generation of numerical models to produce high resolution data sets. Examples are also included in Table 2.1.

These data sets are primarily used by atmospheric scientists for model development and testing. However, impact analysts and scenario developers are increasingly finding uses for such data, for instance, by examining observed relationships between reanalysed upper air fields and surface variables to produce regional climate scenarios downscaled from GCM outputs (e.g. Kaas and Frich, 1995). It should be noted, however, that some reanalysis variables, especially precipitation, are unreliable and should not normally be used as proxies for observed climate data (Widmann and Bretherton, 2000)

Table 2.1 Some public domain sources of baseline climatological data (illustrative; not comprehensive). Links to many of these sites can be found at the IPCC Data Distribution Centre: http://ipcc-ddc.cru.uea.ac.uk/cru_data/examine/ddc_climate.html

Type of baseline data	Source
Various types	World Data Center - A, Meteorology
Observed climate	The CRU Global Climate Dataset (IPCC Data Distribution Centre) Global Historic Climatology Network (GHCN) International Research Institute for Climate Prediction/Lamont-Doherty Earth Observation at University of Columbia British Atmospheric Data Centre (BADC) Global Precipitation Climatology Centre (GPCC) National Centre for Atmospheric Research (NCAR) Data Support System Climatic Research Unit (CRU) data Climate Diagnostics Centre at NOAA Comprehensive Ocean-Atmosphere Data Set (COADS) at NOAA
Reanalysis data	NCEP Re-analysis Data ECMWF
GCM control simulations	IPCC Data Distribution Centre
Weather generators	LARS Weather generator ClimGen Climatic Data Generator

Outputs from GCM control simulations: Another model-based source of information on the present-day climate is multi-century control simulations from AOGCMs. These simulations attempt to represent the dynamics of the global climate system unforced by anthropogenic changes in atmospheric composition. For some regions and on some time-scales these model estimates of natural variability are quite similar both to observations (Tett *et al*., 1997) and to climatic fluctuations reconstructed from proxy records over the past millennium (Jones *et al*., 1998). Since observations with a reasonable global coverage barely extend beyond one century in duration, model control simulations offer an alternative source of data enabling impact analysts to investigate the impact of multi-decadal variations in climate. Control simulation data from seven AOGCMs are currently available from the Data Distribution Centre.

2.1.3.4 Weather generators

A fourth method of characterising the baseline climate is to apply stochastic weather generators (see Box 1). These are computer models that generate synthetic series of daily or sub-daily resolution weather at a site conditional on the statistical features of the historically observed climate. The use of a weather generator (WG) offers several advantages in impact assessment, including:

- The possibility to substitute large quantities of daily observational station data, which are often required as an input to impact models, with a simple model requiring a few parameters describing the statistical properties of the distributions of these values.
- The opportunity to obtain representative weather time series in regions of data sparsity, by interpolating observed data.
- The ability to generate time series of unlimited length, which may be useful in long-term (e.g. multiple-century) or ensemble simulations with impact models. Note, however, that few WGs are capable of accurately reproducing observed inter-annual and longer-term variability (e.g. El Niño/Southern Oscillation events).

- The option to alter the statistical characteristics (parameters) of selected variables according to scenarios of future climate change, representing not only mean changes but also changes in climatic variability.

There are also potential limitations or hazards in using weather generators that should be noted:

- They are seldom able to describe all aspects of the climate accurately, especially persistent events like droughts and warm spells, rare events like heavy rainfall and decadal- or century-scale variations.
- They rely on statistical correlations between climatic variables derived from historical observations that may not be valid under a changed climate.
- They are designed for use, independently, at individual locations and few account for spatial correlation of climate (see Box 1).

There are several well documented WGs available in the public domain that are available for use by impact analysts. Two of these are also included in Table 2.1.

Summary - sources of baseline climatological data: *It is not possible in this document to describe the characteristics of each dataset or procedure that can be used to represent the baseline climate. These are described with the source material. A few datasets are listed in Table 2.1. However, the following questions should be considered when accessing and applying such data or approaches:*

- *Are the original data sources, or the approach, well documented?*
- *Have the data been quality controlled and, if so, how?*
- *Have the original data been corrected, transformed, homogenised or modified in any way?*
- *Is there published information describing the dataset or approach and comparing it with others?*

BOX 1: STOCHASTIC WEATHER GENERATORS

Description

A stochastic weather generator (WG) produces synthetic time series of weather data of unlimited length for a location based on the statistical characteristics of observed weather at that location. Models for generating stochastic weather data are conventionally developed in two steps (Hutchinson 1987). The first step is to model daily precipitation and the second step is to model the remaining variables of interest, such as daily maximum and minimum temperature, solar radiation, humidity and windspeed conditional on precipitation occurrence. Different model parameters are usually required for each month, to reflect seasonal variations both in the values of the variables themselves and in their cross-correlations.

The "Richardson" and "serial" types

Perhaps the best known approach for developing weather generators was reviewed by Richardson (1981), and WGs based on the approach are often referred to as the "Richardson-type". At the first step, the estimation of precipitation involves first modelling the occurrence of wet and dry days using a Markov procedure, and then modelling the amount of precipitation falling on wet days using a functional estimate of the precipitation frequency distribution. The remaining variables are then computed based on their correlations with each other and with the wet or dry status of each day. The Richardson-type of generator has been used very successfully in a range of applications in hydrology, agriculture and environmental management.

One criticism of the Richardson-type WG is its failure to describe adequately the length of dry and wet series (i.e. persistent events such as drought and prolonged rainfall). These can be very important in some applications (e.g. agricultural impacts). For this reason an alternative, "serial approach" has been developed (Racsko *et al*., 1991), which first models the sequence of dry and wet series of days and then models other weather variables like precipitation amount and temperature as dependent on the wet or dry series.

Using WGs in impact assessment

The decision to apply a weather generator in an impact assessment may be determined by one or more of the following requirements:

- Long time series of daily weather, which are not available from observational records
- Daily weather data in a region of data sparsity
- Gridded daily weather data for spatial analysis (e.g. of risk)
- The ability to investigate changes in both the mean climate and its inter-daily variability

Once the decision is made, a suitable WG should then be selected. The criteria for selection will depend upon what models are available and how their documented features suit the needs of the impact assessment. It may be necessary to test a number of models to assess their suitability.

After selecting a model, several steps of analysis are required to parameterise and test the WG:

1. *Data collection* - observed daily climatological data for the variables and site(s) of interest should be collected, quality controlled and correctly formatted. If the WG is to be parameterised for a 1961-1990 baseline period, as much data as possible from this period will be required. On the other hand, if it important to model low frequency, high magnitude events, it will be desirable to obtain the longest possible observed time series. For spatial applications, between-site consistency of the observational time period may also be important.
2. *Parameterisation* - the parameters of the model are estimated using methods documented for the weather generator. If spatial analysis is also being undertaken, this will require parameter estimation at many sites and subsequent interpolation of the parameters to a grid or other spatial field. Some WG programs have automatic procedures for parameter estimation.
3. *Model testing* - time series of weather are generated and their statistics analysed and compared with the observed data on which they were based. The significance of any discrepancies between the WG-derived and observed series can be assessed by running both series through an impact model. Again, automatic model testing procedures are built in to some public domain WG programs.
4. *Climate scenarios* - if the WG is to be used to create weather time series representing a changed climate, procedures will also be required for applying climate change information (e.g. on climate variability change from GCMs) as adjustments to the parameters of the WG. Some WG software also handles climate scenarios.

Applying WGs over space

Weather generators using different approaches have been tested and applied in climate impact assessment (e.g. Wallis and Griffiths, 1995; Harrison *et al*., 1995), and the approaches have also been compared (e.g. Johnson *et al.*, 1996; Semenov *et al*., 1998). While they are most commonly applied at sites, methods have also been developed to interpolate the site parameters of WGs over space, facilitating spatial analysis (e.g. of risk). However, because WG time series are usually site-independent and ignore the observed spatial correlation of climate, this can limit the value of some spatial impact assessments.

For example, a WG may simulate the occurrence of 3 prolonged droughts in a 30 year time series at location A. It may also simulate the same number of droughts at a nearby location B, but in different years. On the other hand, the observed climate at both locations may also show three drought years, but it is likely that these are the same years at both locations, since drought is commonly a widespread phenomenon. Thus, while the WG may provide an accurate statistical representation of the observed situation at each individual site (i.e. the risk of drought and its local impact), taken together, the droughts are not simultaneous and the aggregate impact (e.g. on water resources or agriculture) is likely to be less severe than in the real situation, where widespread drought affects a large area.

A further discussion of this problem and of efforts being made to develop stochastic space-time weather models can be found in Hutchinson (1995).

2.1.4 Applying baseline climatological data

The primary objective in applying baseline data in an impact assessment is to characterise the sensitivity of the exposure unit to present-day climate. This commonly involves first, using part of the data to calibrate and test impact models and second, running the models with input data from the entire baseline period to estimate reference impacts.

Once the baseline data have been obtained, there are several options available for applying them in an impact assessment. A number of these are described below.

2.1.4.1 Extreme event analysis

Analysis of the baseline climate is a key step in studies that focus on the vulnerability of an exposure unit to climatic variability. Both the impacts themselves and possible adaptive responses to climatic variability are often closely related to the magnitude and frequency of extreme events. Thus, a special focus on these events is often merited in the baseline analysis. Three possible options include:

- <u>A focus on the absolute climatic extreme in the record</u> (e.g. a drought, cold year, heavy rainfall event, gale), which might be justified, for example, if the frequency of such events is anticipated to increase in the future. It might be defined directly, as an extreme in the observational climate record, or from a climatic index (e.g. the Southern Oscillation Index to indicate El Niño events). Alternatively, it could be defined as the climatic conditions responsible for an extreme impact, either recorded or simulated.
- <u>A focus on infrequent but recurrent extreme events</u>, which are anomalies that occur more frequently than the absolute extremes, but still cause significant impacts. Due to their greater frequency, they may be more important in shaping the adaptive responses of an exposure unit (for example, the effects of typhoons in low lying coastal areas). Any increase in their frequency might have damaging, perhaps irreversible effects. For example, a previous set of studies on the effects of drought on agriculture in semi-arid regions focused on the 1-in-10 year anomaly (Parry *et al*., 1988).

- A focus on consecutive anomalies, the impacts of which by themselves might be absorbed by an exposure unit, but in succession may have disproportionately greater consequences. For example, one year of drought may force a subsistence farmer to draw on savings or take out loans to pay for the following year's seed, relying on a good crop the following year to make up the shortfall. In this case, a second drought-related crop failure can lead to financial ruin. An example of recent clustering in precipitation and temperature anomalies in the United Kingdom, which has imposed severe stress on the level and distribution of water resources, is presented by Marsh and Turton (1996)

The selection of extreme events is illustrated in Figure 2.1, from a study conducted in Ecuador (Bravo *et al*. 1988). Here, wet and dry events are defined by the October-June rainfall (delimiting the planting season). Rainfall amounts for the baseline period 1964-1983 were ranked from lowest to highest, and plotted on probability paper. The anomalous events selected here were: absolute extremes (note that the wet extreme represents the 1982-1983 El Niño event), and other infrequent anomalies or average events selected using the theoretical probabilities represented by the straight line (10, 35, 50, 65 and 90 percentiles).

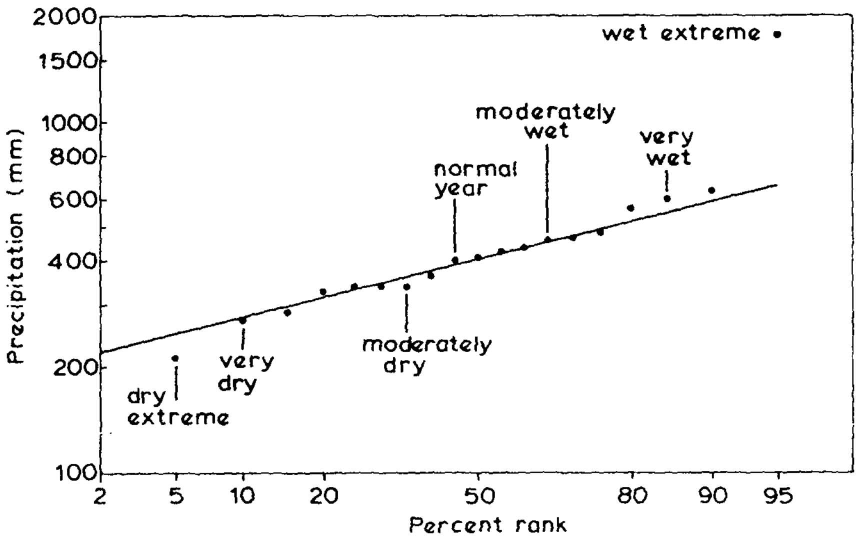


Figure 2.1 Scenarios of October-June precipitation at Palmeira, central Ecuador. Source: Bravo *et al*. (1988).

2.1.4.2 Applying time series of baseline observations

Probably the most common method of defining the baseline climate is to apply climatic time series for a 30-year period either at individual sites or interpolated to a grid. In cases for which a longer period baseline than 30 years is required (for example, to estimate the growth of trees or the risk from storm surges) one option is to apply long-term observations, if they are available. More commonly they are not, so a second option might be to apply a repeating observed 30-year baseline time series over the required time period. Problems with this approach include the possibility that trends or cycles in the baseline period are repeated (unrealistically) throughout the extended series, as well as the likelihood that the 30-year baseline period does not encompass the full range of climatic variability that might be expected in a longer-term series.

2.1.4.3 Applying time series of synthetic data

In impact studies that make use of synthetic time series from weather generators, an important distinction needs to be made between the *precision* and the *accuracy* of the generated statistics. Since there is a random component in the selection of values, the statistics of one time series can differ from those of another of identical length for the same location. The magnitude of this difference depends on the variable in question and the length of the series. As the time series is lengthened, its statistics will converge to a stable set of values (i.e. the precision will be improved). In contrast, the accuracy of the time series describes how well the series reproduces the statistics of the corresponding observations. This can be evaluated by comparing the statistics of very long (and precise) synthetic series with the observed series.

Thus, while the accuracy of the WG can only be improved by modifying the generator itself, the precision of the time series can be enhanced by employing a longer time series. Specifying a suitable length of series often involves a compromise between, on the one hand, obtaining an acceptable precision for the climatological data (and the impacts derived from these data) and, on the other hand, maintaining the volume of data generated at a manageable level. This compromise is of particular importance when generating time series of data regionally, over a regular grid. In this case, the spatial coherence of the generated climatic statistics and of the computed regional impacts is closely dependent on the precision of the time series. Note that spatial coherence refers here to long-term climatic statistics rather than daily weather. As explained in Box 1, most WGs produce a daily weather series at a point that is independent of the series at neighbouring locations.

For example, studies with a Richardson-type WG have shown that while about 100 years of generated data were sufficient to obtain an acceptable level of precision in estimates of baseline (1961-1990) air temperature at a site in Finland, at least 300 years of data were required for precipitation, the frequency distribution of which is more difficult to model. Moreover, to obtain spatially coherent regional statistics on the modelled risk of potato late blight, about 1000 years of generated data were required (Carter and Saarikko, 1996).

2.1.4.4 GCM control simulations and baseline climate

A mention should also be made of the analysis of outputs from the control simulations of GCMs in relation to the baseline climate in a region. Two points can be noted, which relate to GCM validation and use of the GCM control in impact assessments.

- GCM validation: One of the criteria commonly used in selecting a GCM to be used in constructing regional climate scenarios for impact assessment is the performance of the GCM in simulating the present-day climate in the region. This is evaluated by comparing the model outputs with observed climate in the target region, and also over larger scales, to determine the ability of the model to simulate large-scale circulation patterns. For a more detailed discussion, see Section 5.1.3.

- Use of the GCM control in impact assessments: In most impact applications, the baseline climate is represented by observations or synthetic data based on observations. GCM information is only used to define the change in climate between the present-day and some future condition. However, data from GCM control simulations have been applied directly as the input to impact models in a few exploratory studies (e.g. Mavromatis and Jones, 1999). Furthermore, century-scale control simulations have been used to characterise the natural variability of climate that shorter observational time series cannot show. For example, a recent impact study estimated the simulated runoff and wheat yields across

Europe for the baseline observed climate, 1961-1990, using a hydrological model and a crop growth simulation model (Hulme *et al*., 1999a). The baseline climate was then adjusted according to the variations in climate between eight, non-overlapping 30-year periods of an AOGCM control simulation. The range of results based on these eight plausible baseline climates was then compared with estimates of runoff and yield under a changing climate, to establish whether the impacts of anthropogenic climate change were significantly different from the impacts under natural climatic variability.

Summary - applying baseline climatological data: *Much can be learnt about the sensitivity of an exposure unit to climatic variability with the careful and judicious application of baseline climatological data. However, if synthetic or modelled data are being applied to characterise the baseline climate, great care should be exercised in interpreting and applying these data. They can never substitute fully for real observations and may introduce significant errors into the impact response.*

2.1.5 Accessing baseline climatological data from the Data Distribution Centre

The DDC cannot meet all the possible demands for observed climate data that impacts assessors may need. What is provided are pointers to some existing climate data sets that are in the public domain, as well as access to a new gridded global land climate data set and some analysis and plotting tools.

The Climatic Research Unit (CRU) Global Climate Data Set contains gridded monthly surface climate variables for the period 1901-1995 and is described in Box 2. The data set can be viewed using the DDC "Data Visualisation" software, and selected components of the data set can be downloaded. The CRU Global Climate Data Set can be used to examine climate variability over the twentieth century, to evaluate the simulations of various GCMs over the period 1961-1990 (see section 5.1.3) and to combine observed data with GCM projections. Some of the options available include:

- Viewing observed fields, which are maps of observed surface climate variables over land areas for 1961-1990 and other periods. It is also possible to compare the observed fields with modelled 1961-90 mean fields projected onto the same grid.
- Viewing observed time series, which enables time series plots of observed climate to be displayed for the period 1901-1995 for a user-defined region of the global land surface, and for a selection of variables and months or seasons.
- Viewing observed and GCM fields combined, which allows the user to combine the observed 1961-90 global land fields with a user-defined GCM change field to generate a future climate field for any time-slice and variable.

A list of other climatological data sets is also included in the DDC (with links to Web sites on the Internet - and see Table 2.1). The list is not comprehensive, and is continually being updated. Moreover, its inclusion implies no judgement about the validity or reliability of the data, nor does it imply that these data sets have been "approved" by the IPCC. Users should make their own evaluation based on the available documentation and provenance of each data set.

BOX 2: THE CRU GLOBAL CLIMATE DATA SET

The CRU Global Climate Data Set, available through the IPCC DDC, consists of a multi-variate 0.5º latitude by 0.5º longitude resolution mean monthly climatology for global land areas, excluding Antarctica. Together with a mean climatology, which is strictly constrained to the period 1961-1990, there is a monthly time series at the same resolution for the period 1901-1995 (New *et al*., 2000). The mean 1961-1990 climatology comprises a suite of eleven surface variables: precipitation (PRE) and wet-day frequency (WET); mean, maximum and minimum temperature (TMP, TMX, TMN); vapour pressure (VAP) and relative humidity (REH); sunshine percent (SUN) and cloud cover (CLD); frost frequency (FRS); and wind speed (WND). The time series component comprises all variables except sunshine per cent, frost frequency and wind speed. These are still under development.

The mean 1961-90 climatology

The mean climate surfaces have been constructed from a new data set of station 1961-1990 climatological normals, numbering between 19,800 (precipitation) and 3615 (wind speed). The station data were interpolated as a function of latitude, longitude and elevation using thin-plate splines. The accuracy of the interpolations were assessed using cross-validation and by comparison with other climatologies (New *et al*., 1999). Examples of mean temperature and precipitation surfaces are shown (below) in Figure B2.1.

The anomaly time series

The anomaly time series were constructed using historic anomalies derived from the monthly data holdings of the Climatic Research Unit and the Global Historic Climatology Network (GHCN). For the purposes of developing monthly gridded time series, the variables were classified as either primary or secondary. For the primary variables - PRE, TMP, TMX, TMN - sufficient data were available to enable interpolation directly from the station time series. In the case of secondary variables - CLD, VAP, REH, WET - the available station time series were sparsely sampled in space and time. These variables had to be derived indirectly from gridded time series of primary variables. Station data that were available for secondary variables were used to develop relationships to the primary variables, and to validate the derived gridded time series.

The full global climate data set

To calculate monthly time series, grids of monthly anomalies relative to 1961-90 were calculated for each variable and applied to their respective 1961-90 climatology. The anomaly approach was adopted because the network of station normals was much more comprehensive than the network of station time series. The spatial variability in mean climate was best captured by the denser network of station normals, while the more sparse network of primary variable time series captured as much temporal variability as possible.

Viewing and availability

Selected fields and time series from this climatology can be viewed through the Data Visualisation pages of the DDC. Decade-mean and 30-year mean monthly fields can also be downloaded. Access to the full year-by-year monthly dataset is achieved by lodging a request with the Climate Impacts LINK Project at the Climatic Research Unit.

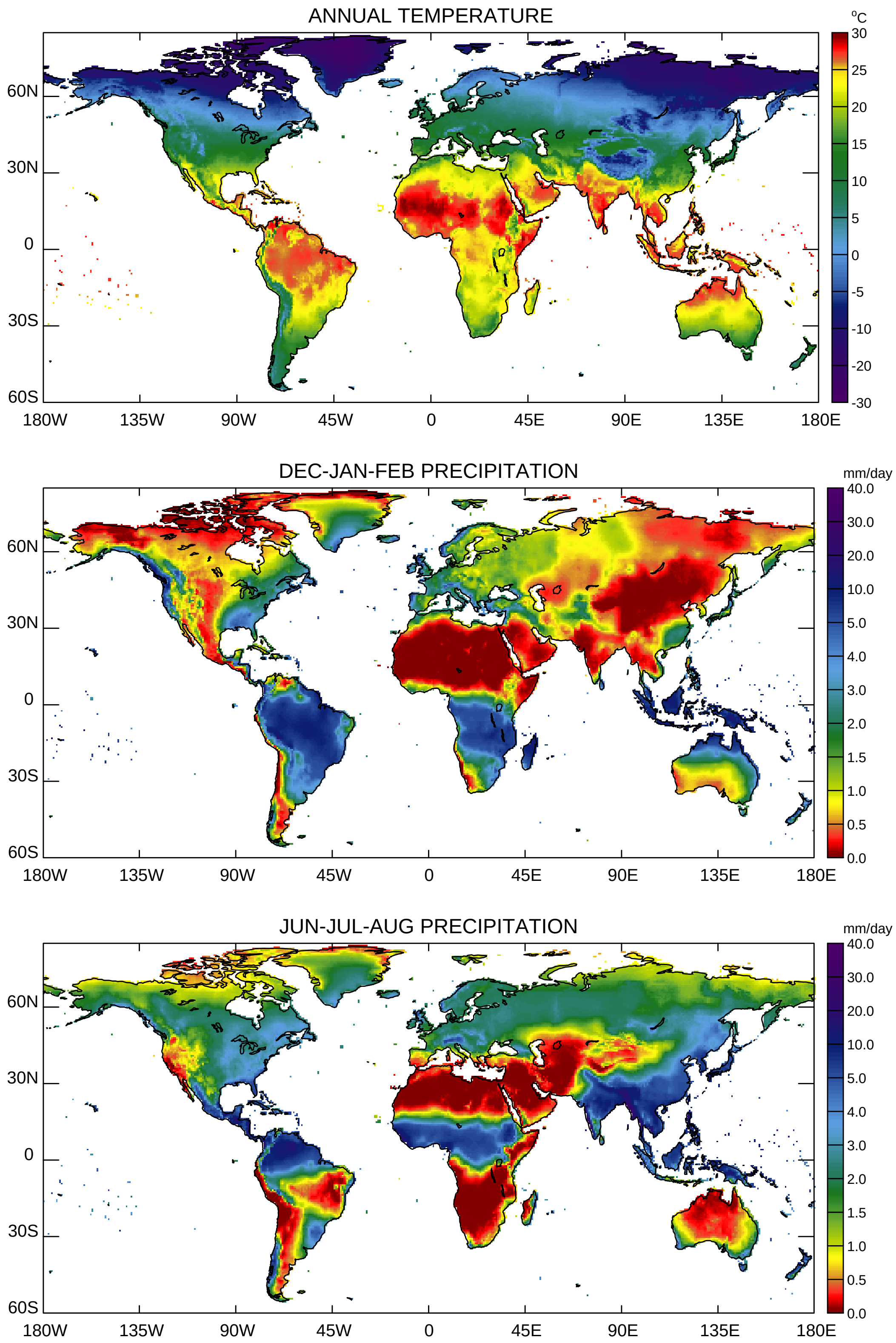


Figure B2.1 Observed global land mean climate fields for 1961-1990 extracted from the New *et al.* (1999) data set. Top: annual mean temperature (°C); middle: December-February mean precipitation rate (mm d^{-1}); bottom: June-August mean precipitation rate (mm d^{-1}). Source: Hulme *et al.* (1999b).

2.2 Non-climatic baselines

Of comparable importance to defining the climatological baseline is a specification of reference values for non-climatic conditions that affect an exposure unit. These can be subdivided into two types: socio-economic and environmental baselines.

2.2.1 Socio-economic baselines

The socio-economic baseline describes the present state of all the non-environmental factors that influence the exposure unit. The factors may be geographical (such as land use or communications), technological (pollution control, water regulation), managerial (forest rotation, fertiliser use), legislative (water use quotas, air quality standards), economic (income levels, commodity prices), social (population, diet), or political (land set-aside, land tenure). All of these are liable to change in the future, so it is important that baseline conditions of the most relevant factors are noted, even if they are not required directly in impact studies.

Note that many of these factors are the basic drivers of changes in the environment and in the climate. For instance, land clearance and the exploitation and combustion of fossil fuels, which have both contributed to increasing greenhouse gas concentrations, are two factors that have resulted from the demands of a rapidly growing global population and economy.

The IPCC has published a set of baseline statistics for 195 countries that are representative of the early to mid 1990s. The data were collated from a variety of sources, such as the World Bank, UNEP and FAO, and they comprise a range of factors organised into seven categories (IPCC, 1998):

- Population and human development: total population, current and projected (2025) population density, total urban population, urban population in coastal cities
- Economic Conditions: GDP per capita, GDP from agriculture, from industry and from services, GDP annual growth rate
- Land cover/land use: total land area, arable and permanent cropland, permanent pasture, forest and woodland, other land
- Water: water resources per capita, annual withdrawals for domestic, industrial and agricultural use
- Agriculture/food: irrigated land, agricultural labour force, total labour force, stocks of cattle, sheep, goats, pigs, equines, buffalo and camels
- Energy: total commercial energy consumption, traditional fuel consumption, commercial hydroelectric consumption
- Biodiversity: known and endemic mammal, bird and plant species

These tabulated data are also available from the Data Distribution Centre. Clearly these are only selected, summary data and individual impact studies are likely to require information on other factors or at a higher spatial resolution. The original sources of the IPCC data set may be able to provide additional country-level information. Otherwise, national or regional sources of data will need to be accessed.

2.2.2 Environmental baselines

Concurrent with variations in climate, there are also variations in other environmental conditions that can have a direct effect on an exposure unit. Strictly speaking, the baseline period for these ought to be consistent with that of the climatological baseline. In fact, many impact studies assume environmental conditions to be fixed at constant values representative of a single year. For instance, in previous IPCC assessments, 1990 has been designated as the reference year.

Some of the more important environmental factors are outlined below under three categories: atmospheric, water and terrestrial conditions.

2.2.2.1 The atmospheric environment

Carbon dioxide: A number of gases and other atmospheric constituents may have important effects on the exposure unit. Perhaps the most important of these is carbon dioxide. CO_2 is well mixed in the atmosphere, so observations of concentrations from a single site (e.g. see Table 2.2, below) are adequate for most impact applications.

Table 2.2 Annual- and decadal-mean CO_2 concentrations (ppmv) observed at Mauna Loa, Hawaii (1959-1998). 1961-1990 mean concentration is 333.4 ppmv. Source: CDIAC (1998).

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Ave.**
1950	-	-	-	-	-	-	-	-	-	315.8	-
1960	316.7	317.5	318.3	318.8	319.4	319.9	321.2	322.0	322.9	324.5	320.1
1970	325.5	326.2	327.3	329.5	330.1	331.0	332.0	333.7	335.3	336.7	330.7
1980	338.5	339.8	342.0	342.6	344.2	345.7	347.0	348.8	351.3	352.8	345.3
1990	354.0	355.4	356.2	357.0	358.9	360.9	362.6	363.8	366.7	-	-

Carbon dioxide concentration is commonly required as a direct input to models of plant growth, since it can affect both the growth and water use of many plants. Since it is also a major greenhouse gas associated with global climate change, the CO_2 concentration adopted should be consistent with concentrations during the climatological baseline period.

Conventionally, the baseline CO_2 concentration is assumed fixed at a given level. This might be the reference concentration in which plants have been grown in CO_2- enrichment experiments. Alternatively, it might be the default value assumed in an impact model, usually a value representative of the late 20th century. However, a word of caution is necessary when testing impact models for conditions over a 30-year or longer baseline period. CO_2 concentrations have increased rapidly during the 20th century (Table 2.2), and if the exposure unit is responsive to CO_2, this temporal trend should be accounted for. For example, mean CO_2 concentration has increased by 11.5% between 1961 and 1990 (Table 2.2). Model estimates of plant growth and yield in 1961 should thus assume 1961 CO_2 concentration in combination with 1961 climate. For century-long simulations of tree growth, this effect may be even more important.

There may also be some applications in which the seasonal and/or diurnal variation of CO_2 concentration should be accounted for. Data on these variations can be found on the Internet pages and in volumes published by the Carbon Dioxide Data and Information and Analysis Centre (e.g. CDIAC, 1998; Internet address: http://cdiac.esd.ornl.gov/cdiac/). The consistency between CO_2 concentrations and climate projections is discussed further in section 5.5, below.

Tropospheric ozone: Another gas of importance in some impact studies is tropospheric ozone. This is toxic for a wide range of living organisms, its concentrations being highly variable in space and time, registering its highest concentrations over industrial regions under certain weather conditions. Time series of ozone concentrations are available for some regions, especially in developed countries. They are usually expressed in terms of background concentrations and peak concentrations.

Stratospheric ozone: Concentrations of stratospheric ozone have been measured operationally at many high latitude sites in recent years, especially following the discovery of the seasonal "ozone hole" over Antarctica in 1985. Ozone depletion is associated with increased ultraviolet radiation, which can be harmful for life on earth. Daily forecasts of exposure risk to UV-radiation are issued in many countries at mid to high latitudes, especially during the spring and early summer when levels of stratospheric ozone are generally at a minimum.

Sulphur and nitrogen compounds: Concentrations of sulphur and nitrogen compounds, which are both major contributors to acid precipitation in many parts of the world, are also measured in some regions. Furthermore, it has been estimated that sulphate aerosol concentrations in industrial regions have contributed a cooling effect on climate in some regions in past decades, which has counteracted the warming effect of greenhouse gases.

Smoke and particulates: Smoke and other particulate matter in the atmosphere, bi-products of fossil fuel burning, land clearance or other human activities, can have important regional impacts on visibility and human health. These are increasingly being observed using satellites as well as ground based instruments.

2.2.2.2 The terrestrial environment

Land cover and land use: On land, data on land cover and land use change are of great importance in many impact studies. Geographical data and time series have been compiled by a number of research groups working at national, continental and global scale, based on satellite imagery, aerial photographs and ground survey. Many data sets have been collected as part of a major international research effort - the Land Use and Land Cover Change Programme (LUCC) of the International Geosphere Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Environmental Change (IHDP). For instance, a global integrated model, IMAGE 2.0, has been used to study the dynamics of land use change. The model was initialised using baseline land use data from 1970. A continually updated time series of observed global land use up to the 1990s can then be used to test the model's predictions during the period after 1970 (Alcamo *et al*., 1996). National land cover/land use statistics have also been tabulated by the IPCC and are available from the DDC (see Section 2.2.1).

Soil: Baseline information is also commonly required on the state of the soil where this has been changing over time, for example, nutrient status, pH and salinity. Data sources for this information tend to be national or regional in scope.

Agricultural practices: In agriculture, data on farm management practices are of vital importance in describing the reference conditions. This covers, for instance, fertiliser applications, use of pesticides and herbicides, tillage practices, stocking rates and irrigation. Baseline information on these is important, not only because they have been responsible for dramatic increases in productivity in many regions in recent decades, but also because they have contributed to soil erosion or pollution of soils, surface waters and groundwater in many regions. Data for different countries are collected annually by the United Nations Food and Agriculture Organisation (FAO, 1992).

Biodiversity: There has been considerable concern in recent years about the endangerment and loss of natural species, mainly attributable to human activities. There have been a number of national and international initiatives to document and catalogue biodiversity, and baseline statistics representative of the 1990s have been compiled for each country by the World Conservation Monitoring Centre, were published for an IPCC report on Regional Impacts of

Climate Change (IPCC, 1998) and are available from the Data Distribution Centre (see Section 2.2.1).

2.2.2.3 The hydrological environment

Sea-level: One of the key factors to evaluate for many impact studies in low lying coastal regions is the current level of the sea relative to the land. Globally, eustatic sea level (the volume of water in the oceans) appears to have been rising during the past century (Warrick *et al*., 1996). However, there are large regional deviations in relative sea-level from this global trend due to local land movements. Subsidence, due to tectonic movements, sedimentation, or human extraction of groundwater or oil, enhances relative sea-level rise. Uplift, due to post-glacial isostatic rebound or tectonic processes, reduces or reverses sea-level rise (Figure 2.2). The main source of information on relative sea-level is tide-gauge records, and the major global data source is the Permanent Service for Mean Sea Level (PSMSL - Web site: http://www.nbi.ac.uk/psmsl/psmsl.info.html)

As a reference, most studies of vulnerability to sea-level rise use the mean sea-level at a single date. For instance, studies employing the IPCC Common Methodology (WCC'93, 1994) use the level in 1990 (Nicholls, 1995; Bijlsma, 1996). However, to assess coastal vulnerability to sea-level effects, baseline tide gauge and wave height observations are required. These reflect tidal variations in combination with the effects of weather such as severe storms and atmospheric pressure variations.

Inland water levels: The levels of lakes, rivers and groundwater also vary with time, usually for reasons related to the natural balance between water inflow (due to precipitation and runoff) and losses (due to evaporation and seepage). Human intervention can also affect water levels, through flow regulation and impoundment, land use changes, water abstraction and effluent return and large scale river diversions (Arnell *et al*., 1996). Sometimes these fluctuations in levels can be very large (often much larger than mean changes anticipated in the future). Thus, where time series are available, it is important to be able to identify the likely causes of fluctuations (i.e. natural or anthropogenic), as this information could influence the selection of an appropriate baseline period.

Other characteristics: Other important water-related characteristics for which baseline data may be required include water temperatures (surface and at different depths), salinity, dissolved oxygen and dissolved organic carbon.

Summary - non-climatic baselines: *The impacts of variations in socio-economic and environmental factors are often critical in understanding the sensitivity of an exposure unit to climate. Some of these variations are also directly or indirectly associated with the climate. Thus, it is important that their present-day variations are described adequately, and in a manner that is consistent with the description of the baseline climate.*

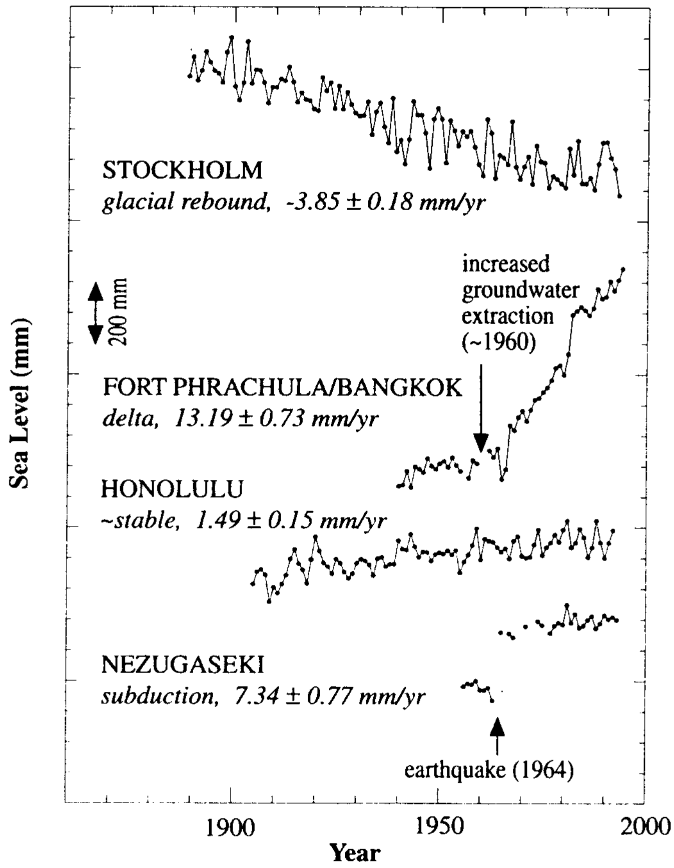


Figure 2.2 Examples of four different trends in observed sea-level change, due to contrasting geological settings. Source: Bijlsma, (1996).

3 DEVELOPING CLIMATE SCENARIOS

Scenarios can be described as pertinent, plausible, alternative futures. Their pertinence, in the case of climate change, is in providing information on how future human activities are expected to alter the composition of the atmosphere, how this may affect the global climate and how changes in climate may affect natural systems and human activities. This information is required to assist decision-makers in controlling future emissions of greenhouse gases and in managing resources that may be affected by climate change. The plausibility of scenarios can only be properly evaluated by scientific analysis and peer review. The Data Distribution Centre and these Guidelines are attempts to assist that process.

The choice of climate scenarios and related non-climatic scenarios is important because it can determine the outcome of a climate impact assessment. Extreme scenarios can produce extreme impacts; moderate scenarios may produce more modest effects (Smith and Hulme, 1998). It follows that the selection of scenarios can also be controversial, unless the fundamental uncertainties inherent in future projections are properly addressed in the impact analysis.

Although the two types are closely related, the development of scenarios is considered under two separate headings in the following two sections: climate scenarios (this section) and non-climatic scenarios (section 4). The interpretation and application of scenarios for impact assessment is examined in section 5.

3.1 What are climate scenarios?

In order to have a basis for assessing future impacts of climate change, it is necessary to obtain a quantitative description of the changes in climate to be expected. Although there is increasing confidence among atmospheric scientists that increased atmospheric greenhouse gas concentrations will increase global temperatures, there is much less confidence in estimates of how the climate will change at a regional scale (IPCC, 1996a). However, it is precisely at this regional or local level (e.g. at the scale of a farm, a river catchment or even an individual organism) that climate change will be felt. Since no method yet exists of providing confident predictions of climate change at these scales, an alternative approach is to specify a number of plausible future climates. These are termed "climate scenarios".

Climate scenarios are plausible representations of the future that are consistent with assumptions about future emissions of greenhouse gases and other pollutants and with our understanding of the effect of increased atmospheric concentrations of these gases on global climate. A range of scenarios can be used to identify the sensitivity of an exposure unit to climate change and to help policy makers decide on appropriate policy responses. It is important to emphasise that climate scenarios are not predictions, like weather forecasts are. Weather forecasts make use of enormous quantities of information on the observed state of the atmosphere and calculate, using the laws of physics, how this state will evolve during the next few days, producing a prediction of the future - a forecast. In contrast, a climatic scenario is a plausible indication of what the future could be like over decades or centuries, given a specific set of assumptions. These assumptions include future trends in energy demand, emissions of greenhouse gases, land use change as well as assumptions about the behaviour of the climate system over long time scales. It is largely the uncertainty surrounding these assumptions which determines the range of possible scenarios.

3.2 Criteria for selecting climate scenarios

Four criteria that should be met by climate scenarios if they are to be useful for impact researchers and policy makers are suggested in Smith and Hulme (1998):

- Criterion 1: Consistency with global projections. They should be consistent with a broad range of global warming projections based on increased concentrations of greenhouse gases. This range is variously cited as 1°C to 3.5°C by 2100 (IPCC, 1996a), or 1.5°C to 4.5°C for a doubling of atmospheric CO_2 concentration (otherwise known as the "climate sensitivity" - IPCC, 1990; 1992).
- Criterion 2: Physical plausibility. They should be physically plausible; that is, they should not violate the basic laws of physics. Hence, changes in one region should be physically consistent with those in another region and globally. In addition, the combination of changes in different variables (which are often correlated with each other) should be physically consistent.
- Criterion 3: Applicability in impact assessments. They should describe changes in a sufficient number of variables on a spatial and temporal scale that allows for impact assessment. For example, impact models may require input data on variables such as precipitation, solar radiation, temperature, humidity and wind speed at spatial scales ranging from global to site and at temporal scales ranging from annual means to daily or hourly values.
- Criterion 4: Representative. They should be representative of the potential range of future regional climate change. Only in this way can a realistic range of possible impacts be estimated.

An additional criterion can be added to this list:

- Criterion 5: Accessibility. They should be straightforward to obtain, interpret and apply for impact assessment. Many impact assessment projects include a separate scenario development component which specifically aims to address this last point. The DDC and this guidance document are also designed to help meet this need.

3.3 Types of climate scenarios

Several types of climate scenario have been used in previous impact studies. These fall into three main classes: synthetic scenarios, analogue scenarios and scenarios based on outputs from GCMs.

3.3.1 Synthetic scenarios

Synthetic scenarios describe techniques where particular climatic (or related) elements are changed by a realistic but arbitrary amount, often according to a qualitative interpretation of climate model simulations for a region. For example, adjustments of baseline temperatures by +1, 2, 3 and 4°C and baseline precipitation by ±5, 10, 15 and 20 per cent could represent various magnitudes of future change. An early illustration of this approach is presented in Terjung *et al*. (1984). Most studies have adopted synthetic scenarios of constant changes throughout the year (e.g. Rosenzweig *et al*., 1996 - see Figure 3.1), but some have introduced seasonal and spatial variations in the changes (e.g. Rosenthal *et al*., 1995), and others have examined arbitrary changes in inter-annual, within-month and diurnal variability as well as changes in the mean (e.g. Williams *et al*., 1988; Mearns *et al*., 1992, 1996; Semenov and Porter, 1995).

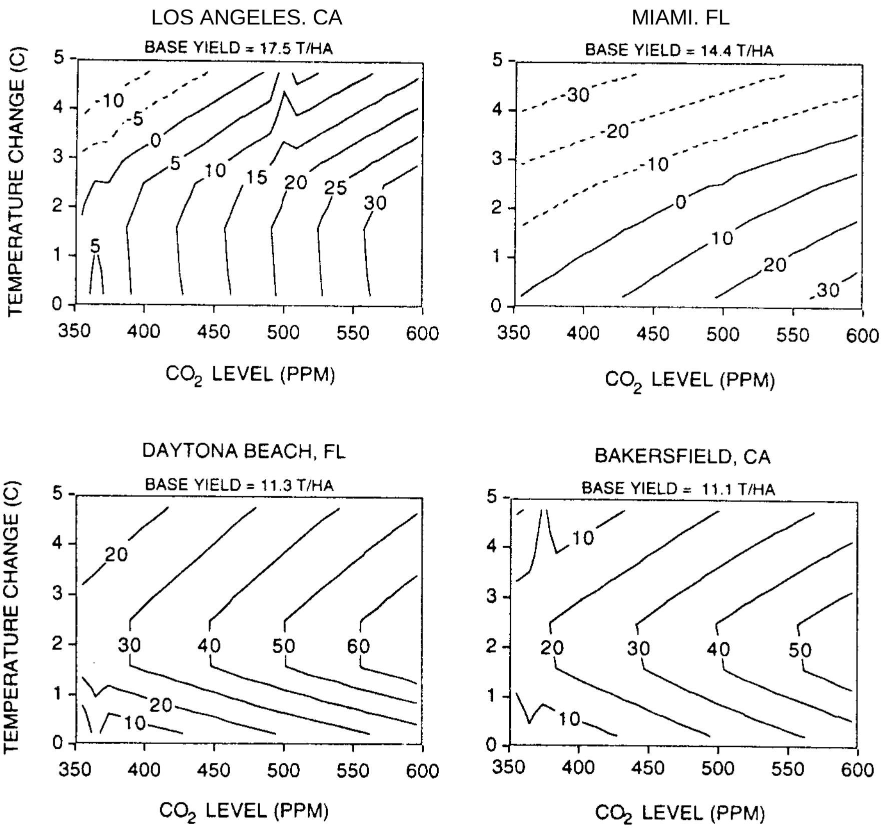


Figure 3.1 Sensitivity of citrus (Valencia orange) yield to elevated temperature and CO_2 concentration at four sites in the United States. Contours indicate percentage yield changes relative to base yields at current temperatures and CO_2 concentration, and are interpolated from means of 28 simulated years for each synthetic scenario combination. Source: Rosenzweig *et al.* (1996)

The advantages of synthetic scenarios are:

- They are simple to apply by impact analysts, transparent and easily interpreted by policy makers and non-specialists (fulfilling criterion 5).
- They capture a wide range of possible changes in climate, offering a useful tool for evaluating the sensitivity of an exposure unit to changing climate (meeting criteria 3 and 4). Since individual variables can be altered independently of each other, synthetic scenarios also help to describe the relative sensitivities to changes in different climatic variables. Moreover, they can assist in identifying thresholds or discontinuities of response that might occur under a given magnitude or rate of climate change. For instance, a small amount of warming might promote the growth of a plant species, but above a critical threshold of warming heat stress may occur.
- Different studies can readily apply the same synthetic scenarios to explore relative sensitivites of exposure units. This is potentially useful for comparing and synthesising the potential effects of climate change over different sectors and regions (cf. Figure 3.1).

The major disadvantage of synthetic scenarios is their arbitrary nature. They seldom present a realistic set of changes that are physically plausible, commonly representing adjustments as being uniform over time and space and inconsistent among variables (hence violating criterion 2). Moreover, some scenarios may be inconsistent with the uncertainty range of global changes (criterion 1). However, this limitation can be overcome if the selection of synthetic scenarios is guided by information from GCMs. The application of "guided sensitivity analysis" is discussed further in Section 5.3, below.

Summary - synthetic scenarios: *Given their arbitrary character, synthetic scenarios rarely present a future climate that is realistic and physically plausible. However, they are invaluable for defining the sensitivity of an exposure unit to a plausible range of climatic variations. Their use in this regard is strongly recommended in impact assessment.*

3.3.2 Analogue scenarios

Analogue scenarios are constructed by identifying recorded climate regimes which may resemble the future climate in a given region. These records can be obtained either from the past (temporal analogues) or from another region at the present (spatial analogues).

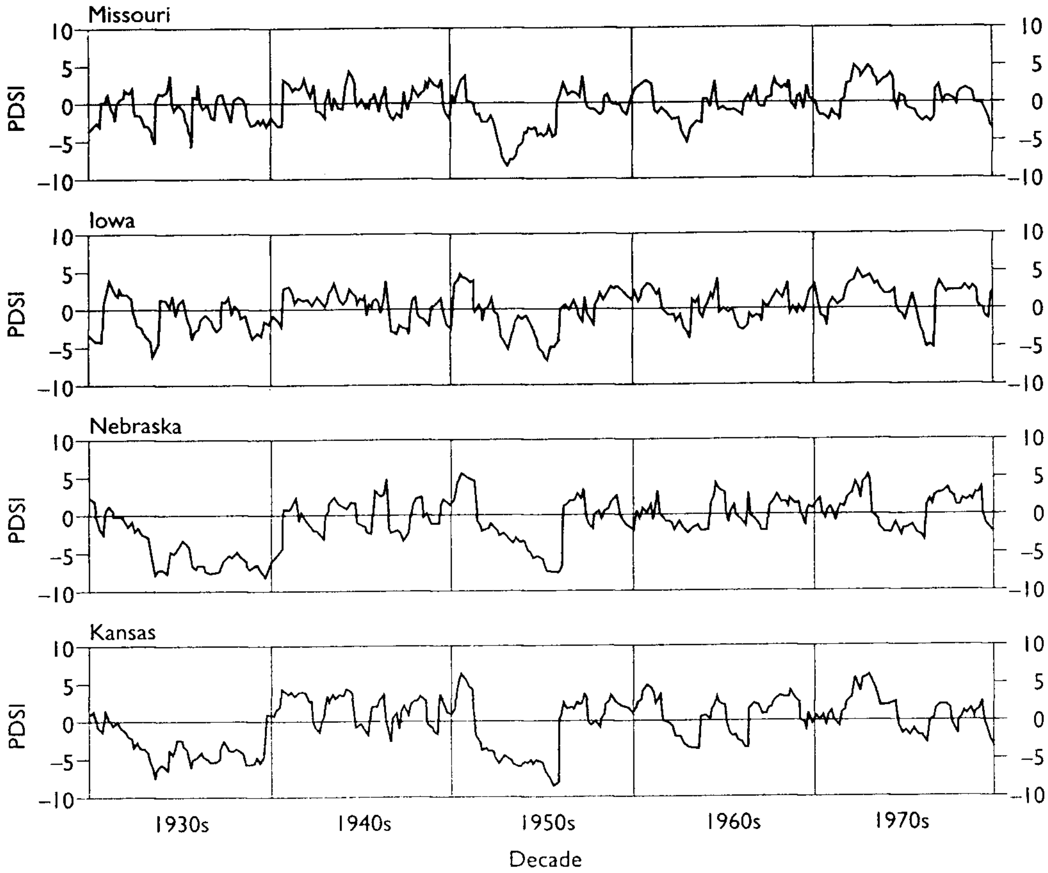
3.3.2.1 Temporal analogues

Temporal analogues make use of climatic information from the past as an analogue of possible future climate. They are of two types: palaeoclimatic analogues based on information from the geological record, and analogues selected from the historical instrumental record, usually within the past century. Both have been used to identify periods when the global (or regional) temperatures have been warmer than they are today. Other features of the climate during these warm periods (e.g. precipitation, wind speed), if available, are then combined with the temperature pattern to define the scenario climate. This can provide a potentially rich data set of observed, and therefore physically plausible, climate (thus satisfying criteria 2 and 3).

Palaeoclimatic analogues are based on reconstructions of past climate from fossil evidence, such as plant or animal remains and sedimentary deposits. Three periods have received particular attention (Budyko, 1989; Shabalova and Können, 1995): the mid-Holocene (5000 to 6000 years BP[*]) - when northern hemisphere temperatures are estimated to have been about 1°C warmer than today, the Last (Eemian) Interglacial (125000 BP) - about 2°C warmer, and the Pliocene (three to four million years BP) - about 3-4°C warmer. During these periods, global temperatures relative to present conditions may have been similar to changes anticipated during the next century (fulfilling, in part, criterion 1).

Instrumentally-based analogues have been used to identify past periods of observed global-scale warmth as an analogue of a greenhouse gas induced warmer world. Scenarios are often constructed by estimating the difference between the regional climate during the warm period and that of the long term average or that of a similarly selected cold period (e.g. Lough *et al*., 1983). An alternative approach is to select the past period on the basis not only of the observed climatic conditions but also of the recorded impacts. A popular example is the dry 1930s period in central North America, which was a period of great hardship coinciding with a depressed economy and widespread soil erosion. It has been adopted in several studies as a possible analogue of future conditions (e.g. Warrick, 1984; Williams *et al*., 1988; Rosenberg *et al*., 1993). For instance, in the Upper Midwest of the United States very dry conditions were accompanied by mean temperatures some 1°C warmer than the 1951-1980 baseline (see Figure 3.2). A further method employs observed atmospheric circulation patterns as analogues, as illustrated by an analysis of the effects of extreme anticyclonic weather on United Kingdom water resources (Wilby *et al*., 1994).

[*] BP = Before Present



Note: negative values indicate water deficiency

Figure 3.2 Palmer Drought Severity Index (PSDI) for the US Corn Belt, 1930-1980. Source: Rosenberg *et al*. (1993)

The major disadvantage of using temporal analogues for climate scenarios is that past changes in climate were unlikely to have been caused by increasing greenhouse gas concentrations (criterion 1). Palaeoclimatic changes were probably caused by variations in the Earth's orbit around the Sun. Changes in the instrumental period, such as the 1930s drought in North America, were probably related to naturally occurring changes in atmospheric circulation.

There are also large uncertainties about the quality of the palaeoclimatic reconstructions (Covey, 1995). None are geographically comprehensive and the dating of material (especially in the more distant past) may not be precise. In addition, they represent the average (often only seasonal) conditions prevailing in the past, It is rare for them to yield concrete information on the variability of climate or frequency of extreme events. Furthermore, in many cases the reconstructed climate represents an equilibrium with respect to long-term processes of vegetation response to climate, which may be quite different in character from the transient climate changes anticipated during the 21st century.

Finally, given that most temporal analogue scenarios (with the exception of the earliest and poorest quality palaeoclimatic analogues) lie towards the low end of the range of anticipated future climatic warming, scenarios based exclusively on analogues may violate criterion 4, as they do not reflect the range of possible future conditions.

3.3.2.2 Spatial analogues

Spatial analogues are regions which today have a climate analogous to the study region in the future. For example, Bergthórsson *et al*. (1988) used northern Britain as a spatial analogue for the potential future climate over Iceland. In this way, modelled estimates of the effects of climatic warming on grass growth in Iceland, based on extrapolation of local relationships, could be compared against the present-day response of grass to temperature and fertiliser application in Britain. The approach is severely restricted, however, by the frequent lack of correspondence between other important features (both climatic and non-climatic) of the two regions (for instance, the daylength in the summer is shorter in northern Britain than in Iceland). Hence, it is unlikely that the present-day combination of climatic and non-climatic conditions prevailing in an analogue region today would be a physically plausible scenarios for conditions in the study region in the future, hence violating criterion 2.

Summary - analogue scenarios: *The main flaw of scenarios that portray future climate by analogy with climate from the past or from another region lies in the causes of the analogue climate. These are almost certainly different from the causes underlying future, greenhouse gas induced climate change. However, these scenarios have the advantage of representing conditions that have actually been observed and experienced, rather than conditions hypothesised by models or expert judgement. The main value of analogue scenarios lies in testing and validating impact models, but it is not ordinarily recommended that they be adopted to represent the future climate in quantitative impact assessments.*

3.3.3 Scenarios from general circulation model outputs

3.3.3.1 General circulation models

Numerical models (general circulation models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations (criterion 1). While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis (IPCC, 1994), thus fulfilling criterion 2.

GCMs depict the climate using a three dimensional grid over the globe, typically having a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans (Figure 3.3). Their resolution is thus quite coarse relative to the scale of exposure units in most impact assessments, hence only partially fulfilling criterion 3.

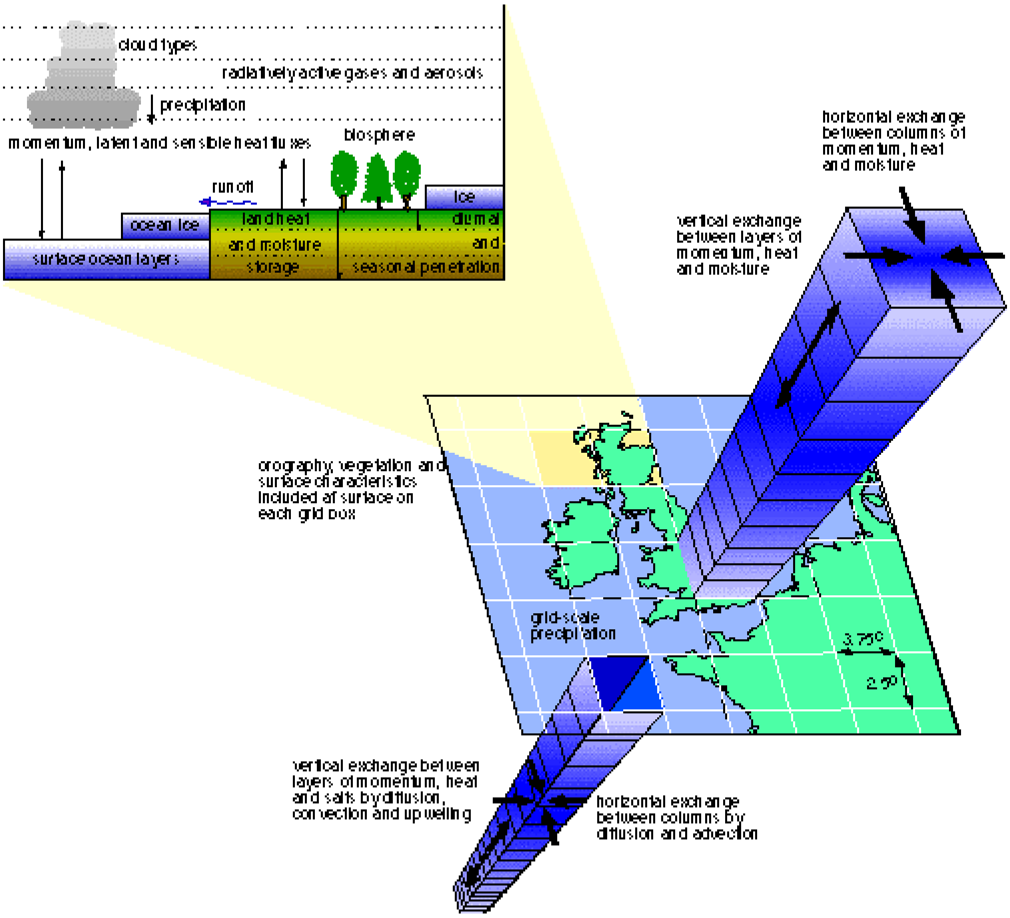


Figure 3.3 Conceptual structure of a coupled atmosphere-ocean general circulation model. Source: Viner and Hulme (1997).

Moreover, many physical processes, such as those related to clouds, also occur at smaller scales and cannot be properly modelled. Instead, their known properties must be averaged over the larger scale in a technique known as parameterisation. This is one source of uncertainty in GCM-based simulations of future climate. Others relate to the simulation of various feedback mechanisms in models concerning, for example, water vapour and warming, clouds and radiation, ocean circulation and ice and snow albedo. For this reason, GCMs may simulate quite different responses to the same forcing, simply because of the way certain processes and feedbacks are modelled.

However, while these differences in response are usually consistent with the climate sensitivity range described in criterion 1, they are unlikely to satisfy criterion 4 concerning the uncertainty range of regional projections. Even the selection of all the available GCM experiments would not guarantee a representative range, due to other uncertainties that GCMs do not fully address, especially the range in estimates of future atmospheric composition. This is discussed further in section 5.

A brief evolution of GCM climate change experiments was sketched in Table 1.1. All models are first run for a control simulation assuming a constant atmospheric composition. Early GCM control runs assumed a CO_2 concentration characteristic of the 1970s or 1980s (e.g. 330 ppm). Control simulations with more recent models assumed pre-industrial levels of greenhouse gases. GCMs have been used to conduct two types of "experiment" for estimating future climate: equilibrium-response and transient-response experiments.

3.3.3.2 Equilibrium-response experiments

Versions of almost all GCMs have been used to conduct experiments to evaluate the equilibrium response (new stable state) of the global climate following an abrupt increase (a doubling or occasionally a quadrupling) of atmospheric CO_2 concentration or its radiative equivalent including all greenhouse gases. These simulations are fairly straightforward to conduct and are useful for intercomparing model results. However, they are not very realistic. The actual change in atmospheric composition is neither continuous nor is it likely to stabilise in the foreseeable future. Furthermore, different parts of the climate system respond differently to radiative forcing and will approach equilibrium at different rates, and may never approximate the composite equilibrium conditions modelled. GCMs used for equilibrium experiments generally have only a very simple representation of the oceans. No results from 2 x CO_2 climate change experiments are provided by the IPCC DDC.

3.3.3.3 Transient-response experiments

The most advanced GCMs are coupled atmosphere-ocean models (AOGCMs), which link, dynamically, detailed models of the ocean with those of the atmosphere. Since these can represent the ocean circulation, AOGCMs are able to simulate the time lags between a given change in atmospheric composition and the response of climate. They can also represent some of the important large scale transfers of heat and moisture attributable to ocean currents. With these features, they can be used in more realistic simulations of the transient-response of climate to a time dependent change in greenhouse gas concentrations. Hence they can provide useful information on the rate as well as the magnitude of climate change. In addition, they have also been used to assess the effects of regional sulphate aerosol loading (a negative forcing) in combination with greenhouse gas forcing.

The earliest transient-response experiments simulated the response of climate to radiative forcing from the present into the future (typically 100 years or more). However, because these failed to account for the historical forcing of rising greenhouse gases during the last century, but rather started the forcing from an assumed equilibrium condition at the present, the GCMs probably underestimated the change in climate during the first few decades beyond the present - the so-called "cold start" problem (Hasselmann *et al*., 1993).

In contrast, the most recent AOGCM simulations begin by modelling historical forcing due to greenhouse gases and aerosols since the eighteenth or nineteenth century ("warm start" experiments), enabling comparisons to be made between modelled and observed climate over this period. Simulations then continue into the future under a scenario of future atmospheric composition, commonly a forcing of 1% per year in equivalent CO_2 concentration (which approximates the radiative forcing expected under the IS92a emissions scenario - see Section 4), with or without aerosols.

The seven models providing results for distribution by the Data Distribution Centre are all of this type (see below). Multiple or "ensemble" simulations have also been conducted with some models to investigate the effect of slightly different, but equally plausible, initial conditions on the climate response to an identical radiative forcing. Examples of these are also available from the DDC.

3.3.3.4 Aerosol experiments

It is only in recent years that the effects of atmospheric aerosols (derived from fossil fuel combustion and biomass burning) on climate have been recognised and included in GCM experiments (e.g. Charlson *et al*., 1992; Taylor and Penner, 1994). Aerosols can affect climate both directly, by scattering and absorbing solar radiation, and indirectly, by altering the properties and lifetime of clouds. The net effect of aerosols is to cool the surface - a negative radiative forcing.

To date, all long term climate simulations include only the direct effect of aerosols. To do this the models must reproduce the geographical variation in aerosol concentrations. Unlike most greenhouse gases, which are well mixed in the atmosphere, aerosol concentrations are greatest over industrial regions, and their patterns can change from decade-to-decade depending on sources and volumes of sulphate emissions.

AOGCM experiments which account for both the negative forcing associated with historically observed concentrations of aerosols and greenhouse gas forcing over the same period have achieved a close correspondence of global mean temperature changes compared to observations (e.g. Mitchell *et al*., 1995; Cubasch *et al*., 1996 - Figure 3.4). These experiments have also been projected into the future on the basis of the assumed concentrations of sulphate aerosols, usually under the assumption of the IS92a scenario SO_2 emissions profiles. The effect on climate when aerosols are included, compared to experiments forced by greenhouse gases only, is to suppress global warming (Figure 3.5). At regional scale the contrast can be even more significant, with a reversal in the sign of precipitation change in some regions (e.g. Mediterranean Europe, Indian monsoon). Nevertheless, towards the end of the 21st century, the effects of greenhouse gas forcing begin to dominate over the aerosol effect.

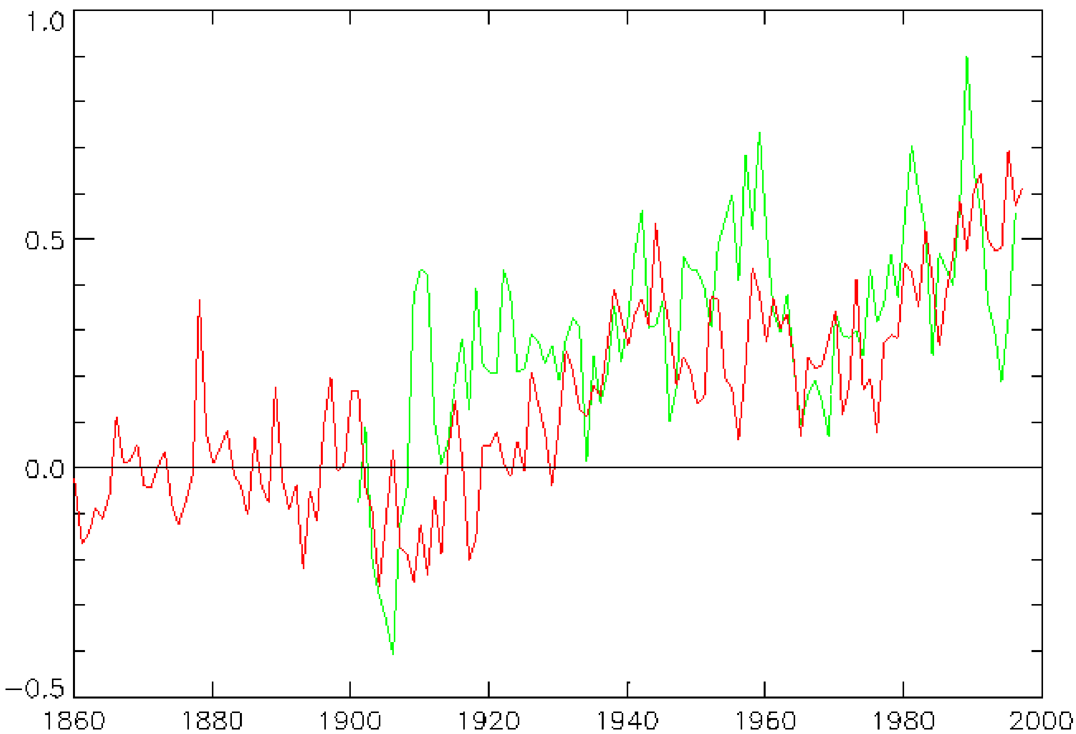


Figure 3.4 Simulations of the global-mean temperature response (°C) (anomalies from 1860-1890 reference period) to historical forcing by greenhouse gases and aerosols by the Hadley Centre AOGCM (HadCM2), 1900-1990 (green). Also shown is the observed record from 1860 (red). Source: Hadley Centre, 1997.

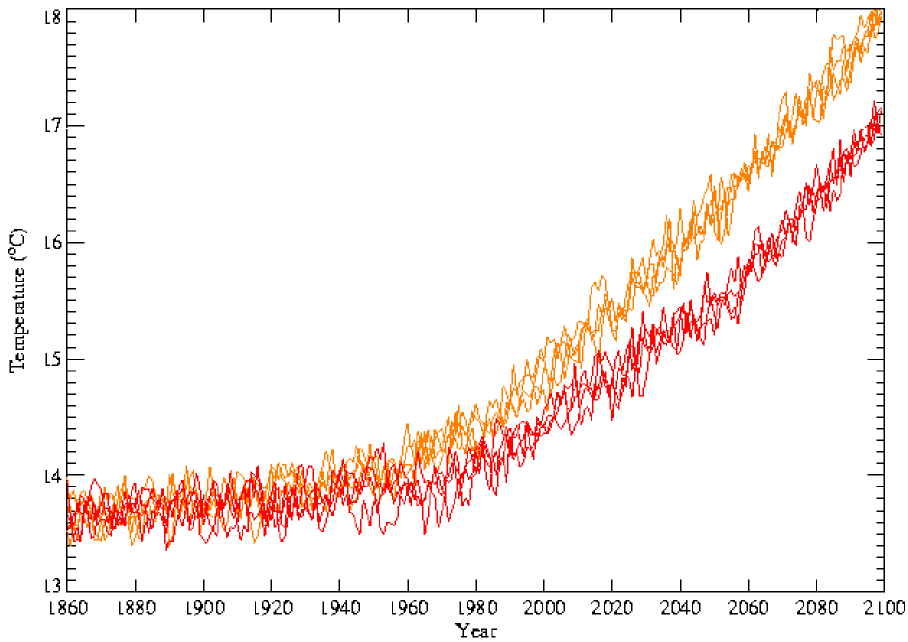
It should be stressed that the sulphate aerosol scenarios assumed in most of these model experiments are now thought to overestimate concentrations. Recent work associated with the IPCC Special Report on Emissions Scenarios suggests that sulphate concentrations will be markedly lower than originally anticipated, due to restrictions on SO_2 emissions in Europe and North America and due to the rapid uptake of newer and cleaner technologies, especially in Asia (A. Grübler, 1997, personal communication). Thus, it seems likely that the sulphate aerosol-induced patterns of climate change in the existing AOGCM aerosol experiments may be very much different from what may turn out to be the case; indeed, with falling SO_2 emissions in most regions in the preliminary, unapproved SRES emissions scenarios, including the effect of sulphate aerosols in AOGCM experiments may actually lead to an additional regional *warming*, rather than a cooling as previously thought (Schlesinger *et al*., 2000). Nevertheless, experiments both with and without aerosols have been included in the Data Distribution Centre (see below), to reflect the state of knowledge from existing experiments.

3.3.3.5 What can be concluded from GCMs about future climate?

As general background information, it is useful to repeat here some of the main conclusions about future climate drawn from the results of GCM experiments conducted to date (Kattenberg *et al*., 1996):

- Greater surface warming of the land than the oceans in winter.
- A minimum warming around Antarctica and in the northern Atlantic associated with deep-water formation.
- Maximum warming at high northern latitutdes in late autumn and winter associated with reduced sea ice and snow cover.
- Little warming over the Arctic in summer.
- Little seasonal variations of warming at low latitudes or over the southern oceans.
- A reduction in diurnal temperature range over land in most seasons and most regions.
- An increase in anomalously high temperature events and a decrease in anomalously low temperatures.
- An enhanced global mean hydrological cycle.
- Increased precipitation at high latitudes in winter.
- Probable increases in intense precipitation events in many regions.

(a)



(b)

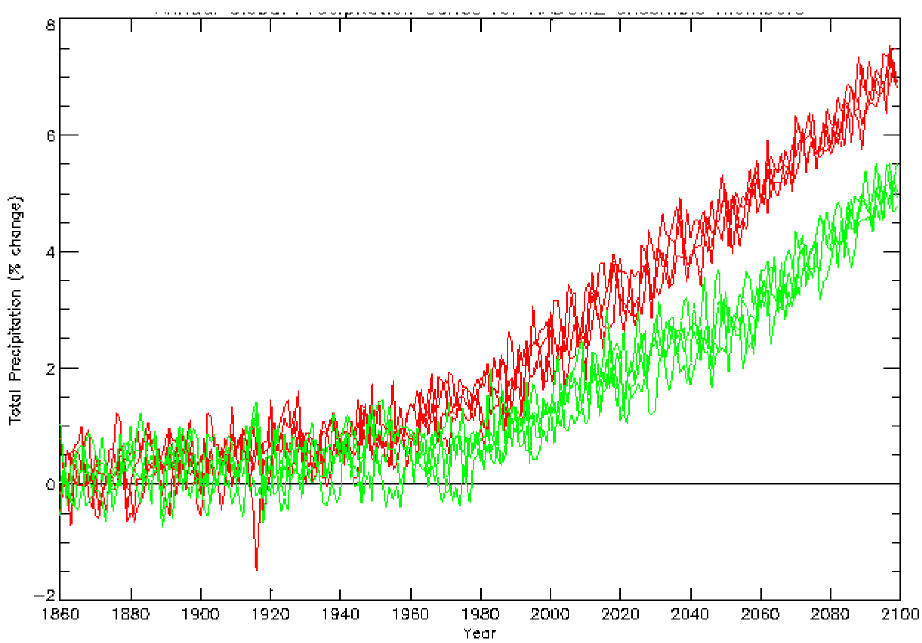


Figure 3.5 Four ensemble simulations of the global-mean climate response to projected increases in greenhouse gases alone (GG) and greenhouse gases and sulphate aerosols combined (GS) by the Hadley Centre AOGCM (HadCM2) for the period 1861-2100: (a) temperature (orange = GG; red = GS) and (b) precipitation (red = GG; green = GS). Source: Hadley Centre (1997).

3.3.3.6 GCM outputs available from the DDC

One of the main goals of the Data Distribution Centre was to make available to the impacts community a set of recent GCM outputs that both reflect the state-of-the-art of model experiments and provide a representative range of results from different GCMs. To this end, the IPCC TGCIA defined a set of criteria that were applied to identify a small number of GCM experiments whose results could be deposited at the IPCC DDC. These experiments could therefore form the basis for impact assessments undertaken during 1998 and 1999 (i.e. prior to the Third Assessment Report). These criteria included:

- An IS92a-type forcing scenario (see section 4)
- Historically forced (warm-start) integrations
- Integrations with and without aerosol forcing and extending to 2100 for greenhouse gas only forcing
- Integrations with results available now and with data lodged in the public domain
- Documented models
- Models that have been included in model intercomparison exercises such as AMIP and CMIP (section 5.2.3)

On the basis of these criteria, an initial selection of experiments from seven modelling centres was made, with the possibility of others being added in subsequent months as they qualified for inclusion. The seven models selected were:

- CCSR - Japanese Centre for Climate Research Studies model (Emori *et al*., 2000)
- CGCM1 - Canadian Centre for Climate Modelling and Analysis GCM #1 (Reader and Boer, 1998; Boer *et al*., 2000)
- CSIRO-Mk2b - Australian Commonwealth Scientific and Industrial Research Organisation, Model #2b (Hirst *et al*., 2000)
- ECHAM4 - German Climate Research Centre, European Centre/Hamburg Model #4 (Roeckner *et al*., 1996; Zhang *et al*., 1998)
- GFDL-R15 - US Geophysical Fluid Dynamics Laboratory, R-15 resolution model (Manabe and Stouffer, 1996)
- HadCM2 - UK Hadley Centre for Climate Prediction and Research Coupled Model #2 (Johns *et al*., 1997; Mitchell and Johns, 1997)
- NCAR-DOE - US National Centre for Atmospheric Research model, DOE version (Meehl *et al*., 2000)

Some characteristics of the seven models and experimental outputs available from the DDC are displayed in Table 3.1. Note that data from ensemble and time slice experiments are also available for some models. Monthly averaged results from each model have been lodged with the IPCC DDC. The following eight surface variables are available from each model experiment: precipitation rate, mean sea-level pressure, solar radiation, mean air temperature, dew point temperature, minimum air temperature, maximum air temperature and 10 metre wind speed.

Other period-averaged information that can be displayed and downloaded using DDC software includes: diurnal temperature range, vapour pressure, daily temperature variance and daily precipitation variance. Some other variables can also be obtained for individual experiments.

The full sets of monthly results from these experiments (and more detailed technical information) can be obtained from the DDC GCM Archive, although daily fields are only available directly from the respective modelling centres. The supporting DDC software allows the user to plot 30-year mean change fields from these experiments, comparing them with each other and with the 1961-1990 observed climatology. Ensemble members can also be plotted, as well as ensemble means. All 30-year mean GCM fields can be downloaded from the DDC.

Summary - scenarios from general circulation models: *GCMs offer the most credible tools for estimating the future response of climate to radiative forcing. Many experiments have been conducted with GCMs, considering both equilibrium and transient responses and accounting for the effects of both greenhouse gases and aerosols. Models largely agree on the expected large-scale pattern of climate change, but there are still important uncertainties in regional projections.*

Table 3.1 Some features of the seven core AOGCMs and the experiments for which data are available from the Data Distribution Centre.

	ECHAM4	**HadCM2**	**CSIRO**	**CGCM1**	**GFDL**	**NCAR**	**CCSR**
AGCM	2.8°x2.8° L19	2.5°x 3.75° L19	3.2°x5.6° L9	3.7°x3.7° L10	4.5°x7.5° L9	4.5°x7.5° L9	5.6°x5.6° L20
OGCM	2.8°x2.8° L11	2.5°x 3.75° L20	3.2°x5.6° L21	1.8°x1.8° L29	4.5°x 3.75° L12	1°x1° L20	2.8°x2.8° L17
Features	prognostic CLW*, geostrophic ocean	prognostic CLW, isopycnal ocean diffusion			no diurnal cycle, isopycnal ocean diffusion	no diurnal cycle	prognostic CLW, explicit sulfate scattering
Flux correction	monthly mean heat, fresh water, stress	monthly mean heat, fresh water	heat, fresh water, momentum	heat, fresh water	monthly mean heat, fresh water	none	monthly mean heat, fresh water
Control CO_2	354 ppmv	323 ppmv	330 ppmv	295 ppmv	300 ppmv	330 ppmv	345 ppmv
Transient CO_2	1.0% yr^{-1} (compound)	1% yr^{-1} (compound)	0.9% yr^{-1}	1% yr^{-1}	1% yr^{-1} (compound)	1% yr^{-1} (linear)	1% yr^{-1} (compound)
Greenhouse Gases	CO_2 : Historic 1860-1989 IS92a : 1990-2099	CO_2 : Historic 1860-1989 IS92a : 1990-2099	CO_2 : Historic 1881-1989 IS92a : 1990-2100	CO_2 : Historic 1900-1989 IS92a : 1990-2100	CO_2 : IS92a : 1958-2057	CO_2 : Historic 1901-1989 IS92a : 1990-2036	CO_2 : Historic 1890-1989 IS92a : 1990-2099
Greenhouse gases + Sulphate Aerosols	CO_2 : Historic 1860-1989 IS92a : 1990-2049 SO_4 : Historic 1860-1989 IS92a : 1990-2049	CO_2 : Historic 1860-1989 IS92a : 1990-2099 SO_4 : Historic 1860-1989 IS92a : 1990-2099	CO_2 : Historic 1881-1989 IS92a : 1990-2049 SO_4 : Historic 1860-1989 IS92a : 1990-2100	CO_2 : Historic 1900-1989 IS92a : 1990-2100 SO_4 : Historic 1860-1989 IS92a : 1990-2100	CO_2 : Historic 1766-1989 IS92a : 1990-2065 SO_4 : Historic 1766-1989 IS92a : 1990-2065	CO_2 : Historic 1901-1989 IS92a : 1990-2036 SO_4 : Historic 1901-1989 IS92a : 1990-2036	CO_2 : Historic 1890-1989 IS92a : 1990-2099 SO_4 : Historic 1890-1989 IS92a : 1990-2099
Simulation length (yr)	Control : 240 Greenhouse : 240 Greenhouse+ Aer : 240	Control : 240 Greenhouse : 240 Greenhouse+ Aer : 240	Control : 219 Greenhouse : 219 Greenhouse +Aer : 219	Control : 200 Greenhouse : 200 Greenhouse +Aer : 200	Control : 1000 Greenhouse : 100 Greenhouse+ Aer : 300	Control : 136 Greenhouse : 136 Greenhouse +Aer : 136	Control : 210 Greenhouse : 210 Greenhouse+ Aer : 210
Warming (°C) at CO_2 doubling	1.3	1.7	2.0	2.7	2.3	2.3 (est.)	2.4
2 x CO_2 sensitivity (°C)	2.6	2.5	4.3	3.5	3.7	4.6	3.5

4 DEVELOPING NON-CLIMATIC SCENARIOS

Regardless of whether or not the climate changes in the future, there is no doubt that changes in socio-economic and environmental conditions will occur. In section 2.2 the baseline conditions of these non-climatic factors were introduced, and some examples presented for different countries. These values represent the present-day or "current" baseline. This section considers projections of how non-climatic factors might change in the future both in the absence of climate change (the "future baseline") and with climate change.

In relation to the non-climatic scenarios provided by the Data Distribution Centre, and for the purposes of this document, the distinction between scenarios with and without climate change is limited to environmental projections, for which changes in atmospheric composition (that affect climate) and relative sea-level rise (a consequence of climate change) are considered separately. Although there are examples of adjustments in socio-economic behaviour that would be expected under a changing climate (adaptations that are sometimes known as "autonomous adjustments"), examination of these is likely to be case specific and they are not considered here.

4.1 Socio-economic scenarios

4.1.1 Why do we need socio-economic scenarios?

The major underlying cause of rapid changes in atmospheric composition is human economic activity, in particular emissions of greenhouse gases and aerosols, and changing land cover and land use. Socio-economic scenarios that project the major driving factors of change are important for several reasons:

- They improve our understanding of the key relationships among factors that drive future emissions.
- They provide a realistic range of future emissions of net greenhouse gas and aerosol precursors, which can be converted to atmospheric concentrations and associated radiative forcing of the atmosphere, which is required in estimating future climate change.
- They assist in assessing the relative importance of relevant trace gases and aerosol precursors in changing atmospheric composition and hence climate.
- They offer a consistent framework of projections (albeit at a global or aggregate regional scale) that can be applied in climate change impact assessments.

A set of scenarios was published by the IPCC in 1992 and a new set is being developed for the Third Assessment Report. These have a projection period out to 2100 (see below). They are described by the IPCC, and for consistency are also labelled here, as emissions scenarios, but they actually comprise a whole set of underlying socio-economic assumptions.

4.1.2 The IS92 emissions scenarios

Six alternative IPCC scenarios (IS92a to f) were published in the 1992 Supplementary Report to the IPCC Assessment (Leggett *et al.*, 1992). These scenarios embodied a wide array of assumptions affecting how future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted. The different worlds that the scenarios imply, in terms of economic, social and environmental conditions, vary widely and the resulting range of possible greenhouse gas futures spans almost an order of magnitude.

The assumptions for the IS92 scenarios came mostly from the published forecasts of major international organisations or from published expert analyses. Most of these were subject to extensive review. The premises for the IS92a and IS92b scenarios most closely resemble and update those underpinning the original SA90 scenario used in the First Assessment Report of the IPCC in 1990. IS92a has been widely adopted as a standard scenario for use in impact assessments, although the original IPCC recommendation was that all six IS92 emissions scenarios be used to represent the range of uncertainty in emissions (Alcamo *et al*., 1995). Population rises to 11.3 billion by 2100 and economic growth averages 2.3 % per annum between 1990 and 2100, with a mix of conventional and renewable energy sources being used. The highest greenhouse gas emissions result from the IS92e scenario that combines, among other assumptions, moderate population growth, high economic growth, high fossil fuel availability and eventual phase out of nuclear power. At the other extreme, IS92c has a CO_2 emissions path that eventually falls below its 1990 starting level. It assumes that population first grows, then declines by the middle of next century, that economic growth is low, and that there are severe constraints on fossil fuel supply.

Table 4.1 summarises some of the main assumptions of the IS92 scenarios at global scale. The Data Distribution Centre also provides tabular listings for nine major world regions. Also shown in Table 4.1 are the atmospheric composition associated with these scenarios, and their climatic and sea-level consequences. The latter estimates were made using a set of simple models described in Box 4.

4.1.3 The SRES emissions scenarios

The IPCC has commissioned a Special Report on Emissions Scenarios (SRES) to generate a new set of scenarios for use in the Third Assessment Report. Preliminary and, as yet (November 1999) unapproved versions of these new scenarios were released in 1998 and have been made available to the DDC for use in climate scenario construction and impact and adaptation assessments. The SRES scenarios have been constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions. They use the following terminology:

- <u>Storyline:</u> a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.
- <u>Scenario:</u> projections of a potential future, based on a clear logic and a quantified storyline.
- <u>Scenario family:</u> one or more scenarios that have the same demographic, politico-societal, economic and technological storyline.

The approach has been to develop a set of four "scenario families". The storylines of each of these scenario families describes a demographic, politico-economic, societal and technological future. Within each family one or more scenarios explore global energy, industry and other developments and their implications for greenhouse gas emissions and other pollutants. One example of each scenario family, termed "marker quantifications", has been provided to users. The scenarios have been built to explore two main questions for the twenty first century, neither of which we know the answer to:

1. Can adequate governance (institutions and agreements) be put in place to manage global problems?
2. Will society's values focus more on enhancing material wealth or be more broadly balanced, incorporating environmental health and social well-being?

Table 4.1 Summary of the IS92 scenarios and their estimated environmental consequences. IS92 emissions used in calculations are taken from IPCC (1994). Model calculations are by the IPCC SAR version of MAGICC (Wigley and Raper, 1992; Version 2.3, May 1997). Changes are with respect to the 1961-90 average. Aerosol effects are included.

Scenario estimates	1990	IS92 scenarios for 2100					
		IS92a	**IS92b**	**IS92c**	**IS92d**	**IS92e**	**IS92f**
Population (billion)	5.252	11.3	11.3	6.4	6.4	11.3	17.6
Economic growth rate (annual GNP; % p.a.)	-	2.3	2.3	1.2	2.0	3.0	2.3
CO_2 concentration (ppmv)[1]	354	708	685	471	542	954	820
Global annual-mean temp. change (°C)[2]	-	2.18	2.13	1.47	1.75	2.64	2.52
Range (°C)[3]	-	1.50-3.14	1.46-3.06	1.29-2.18	1.18-2.56	1.83-3.73	1.74-3.59
Global mean sea-level rise (cm)[2]	-	51	50	40	45	57	56
Range (cm)[3]	-	20-90	20-89	14-76	16-82	24-98	23-96

[1] best-guess assumptions re. C cycle; [2] assuming 2.5ºC climate sensitivity; [3] based on 1.5ºC and 4.5ºC climate sensitivity range.

Although the storylines do not contain explicit climate change policy measures, there are examples of indirect mitigation measures in some of the scenarios. The scenario quantifications of the main indicators related to growth of population and economy, the characteristics of the energy system and the associated greenhouse gas emissions all fall within the range of prior studies.

The DDC provides tabular listings of the four SRES marker quantifications, as well as an interpretation - using the same simple models as were used with the IS92 scenarios above - of what these different scenarios signify for future global temperature and sea-level change. The assumptions underlying these emissions scenarios (i.e. population, economic growth, etc.) are also described. These are summarised globally in Table 4.2.

In simple terms, the four marker scenarios combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization. The storylines are summarized as follows:

- A1: A future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality. For illustration, the storyline developed for the A1 scenario family is described in more detail in Box 3.

- A2: A differentiated world. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.

Table 4.2 Summary of the SRES marker scenarios and their estimated environmental consequences. SRES emissions used in calculations are taken from the preliminary and unapproved version posted on the CIESIN web site, December 1998. Model calculations are by the IPCC SAR version of MAGICC (Wigley and Raper, 1992; Version 2.3, May 1997). Changes are with respect to the 1961-90 average. Aerosol effects are included.

		SRES marker scenarios for 2100			
Scenario estimates	**1990**	**A1**	**A2**	**B1**	**B2**
Population (billion)	5.252	7.1	15.1	7.2	10.4
Economic growth rate (annual GNP; % p.a.)	-				
CO_2 concentration (ppmv)[1]	354	680	834	547	601
Global annual-mean temp. change (°C)[2]	-	2.52	3.09	2.04	2.16
Range (°C)[3]	-	1.70-3.66	2.12-4.41	1.37-2.99	1.45-3.14
Global mean sea-level rise (cm)[2]	-	58	62	50	52
Range (cm)[3]	-	23-101	27-107	19-90	20-93

[1] best-guess assumptions re. C cycle; [2] assuming 2.5ºC climate sensitivity; [3] based on 1.5ºC and 4.5ºC climate sensitivity range.

- B1: A convergent world with rapid change in economic structures, "dematerialization" and introduction of clean technologies. The emphasis is on global solutions to environmental and social sustainability, including concerted efforts for rapid technology development, dematerialization of the economy, and improving equity.

- B2: A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a heterogeneous world with less rapid, and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions.

BOX 3 THE SRES A1 SCENARIO FAMILY

The A1 storyline is a case of rapid and successful economic development, in which regional averages of income per capita converge: current distinctions between "poor" and "rich" countries eventually dissolve. The primary dynamics are a strong commitment to market-based solutions; high savings and commitment to education at the household level; high rates of investment and innovation in education, technology and institutions at the national and international level; and international mobility of people, ideas and technology. The transition to economic convergence results from advances in transport and communication technology, shifts in national policies on immigration and education, and international cooperation in the development of national and international institutions that enhance productivity growth and technology diffusion.

In this scenario, demographic and economic trends are closely linked, as affluence is correlated with long life and small families (low mortality and low fertility). Global population grows to some nine billion by 2050 and declines to about seven billion by 2100. Average age increases, with the needs of retired people met mainly through their accumulated savings in private pension systems.

The global economy expands at an average annual rate of about three percent to 2100. This is approximately the same as average global growth since 1850, although the conditions that lead to global growth in economic productivity and per capita incomes are unparalleled in history. Income per capita reaches about US$21,000 by 2050. While the high average level of income per capita contributes to a great improvement in the overall health and social conditions of the majority of people, this world is not without its problems. In particular, many communities could face some of the problems of social exclusion encountered in the wealthiest countries in the 20th century and in many places income growth could come with increased pressure on the global commons.

Energy and mineral resources are abundant in this scenario family because of rapid technical progress, which both reduce the resources needed to produce a given level of output and increases the economically recoverable reserves. Final energy intensity (energy use per unit of GDP) decreases at an average annual rate of 1.3 percent.

Several variant scenarios have been considered in the A1 scenario family reflecting the uncertainty in development of energy sources and conversion technologies in this rapidly changing world.. These variants have been introduced into the A1 storyline because of its "high growth with high tech" nature, where differences in alternative technology developments translate into large differences in future GHG emission levels.

Ecological resilience is assumed to be high in this storyline. Environmental amenities are viewed in a utilitarian way, based on their influence on the formal economy. The concept of environmental quality might change in this storyline from "conservation" of nature to active "management" (and marketing) of natural and environmental services.

With the rapid increase in income, dietary patterns shift initially significantly towards increased consumption of meat and dairy products, but may decrease subsequently with increasing emphasis on health of an aging society. High incomes also translate into high car ownership, sprawling suburbanization and dense transport networks, nationally and internationally. Land prices increase faster than income per capita. These factors along with high wages result in a considerable intensification of agriculture.

Source: SRES Web site: http://sres.ciesin.org/htmls/storyline_families.html#A1

4.1.4 How are these emissions scenarios used in GCMs?

An important question for climate scenario construction is how these emissions scenarios relate to the forcing scenarios used in the GCM experiments. The GCM simulations held to date on the DDC use stylised forcing scenarios - typically a 0.5 % or 1 % per annum increase in the concentration of equivalent CO_2 in the atmosphere. Thus, in order to obtain a comparison, the detailed gas-by-gas emissions scenarios should be converted to concentrations using information on their atmospheric lifetimes, and then aggregated to achieve CO_2-equivalent concentrations. This can be a tricky procedure, requiring various assumptions about the nature and rate of chemical reactions in the atmosphere, the residence time of different gases, and reference concentrations. More recently, some GCM simulations have discriminated between the effects of individual greenhouse gases, thus requiring concentration scenarios for each gas.

4.2 Environmental scenarios without climate change

It is highly probable that future changes in other environmental factors will occur, even in the absence of climate change, which may be important for an exposure unit. Examples include deforestation, changes in grazing pressure, changes in groundwater level or mean sea-level and changes in air, water and soil pollution. Official projections may exist to describe some of these (such as groundwater level), but for others it may be necessary to study past trends and apply expert judgement. Since most of these changes are local or regional in scale, projections are not provided by the DDC. Most factors are related to, and projections should be consistent with, trends in socio-economic factors (see below). Greenhouse gases may also change, but they are usually linked to climate (which is assumed unchanged here).

4.3 Environmental scenarios with climate change

The two environmental factors that are directly related to a changing climate, and are commonly required in impact assessments, are atmospheric composition and sea-level rise.

4.3.1 Scenarios of atmospheric composition

Projections of atmospheric composition are important for assessing affects, firstly, on radiative forcing of the climate, secondly, on depletion of stratospheric ozone (CFCs), and thirdly, on plant response (CO_2, tropospheric ozone and compounds of sulphur and nitrogen). Scenarios for CO_2 concentrations consistent with the IS92 and provisional SRES socio-economic scenarios (using the simple models described in Box 4) are given in Tables 4.1 and 4.2.

4.3.2 Scenarios of sea-level

One of the major impacts projected under global warming is sea-level rise. Global factors such as the expansion of sea water and melting of ice sheets and glaciers all contribute to this effect. Some of the AOGCMs compute relative sea-level rise, but this is only the portion attributable to thermal expansion of sea water, possibly accounting for no more than about one half of the projected change (Warrick *et al*., 1996). Simple global models that attempt to account for all of these factors can also be used to obtain global estimates. A set of estimates consistent with the IS92 and SRES scenarios and modelled temperature changes (cf. Box 4) are provided in Tables 4.1 and 4.2.

Note that local conditions such as coastal land subsidence, tectonic movements, isostatic uplift, changes in mean atmospheric and oceanic circulation and changes in storminess, waves and tides should also be taken into account in considering the extent of sea-level changes and their regional impacts. Some of these can be projected based on past trends, for example, using tide gauge records (see Section 2.2.2.3).

4.3.3 Other environmental scenarios

Other environmental factors that are directly affected by climate include river flow, runoff, soil characteristics, erosion and water quality. Projections of these often require full impact assessments of their own, or could be included as interactive components within an integrated assessment framework. No projections of these are provided by the DDC.

Summary - developing non-climatic scenarios: *In order to obtain credible estimates of future impacts it is necessary to develop reference projections of a range of important socio-economic and environmental factors which are anticipated to change regardless of global climate. The IS92 and SRES scenarios illustrate some of these plausible "future baselines". However, for the purposes of physical plausibility, there are also non-climatic projections that need to be consistent with estimated climate change. Prominent examples of these are* CO_2 *concentration and sea-level rise.*

5 APPLYING SCENARIOS IN IMPACT ASSESSMENT

Having described some of the options available for developing scenarios and the scenario information available from the DDC, the next vital step in an impact assessment is the selection, interpretation and application of appropriate scenarios. These are discussed in this section, with the main focus on climate scenarios.

5.1 Selecting model outputs

Many climate change experiments have been performed with GCMs. For instance, 24 transient experiments were reviewed by the IPCC (Kattenberg *et al*., 1996), and many more have been conducted since then. The number of completed equilibrium experiments is greater still. Therefore, if GCM-based scenarios are to be constructed, it is not easy to choose suitable examples for use in impact assessments.

There have always been some limitations on the breadth of choice: some experiments may not have been fully archived in an accessible and public form, in some cases the required variables have not been available and in many cases the impact assessors have simply not been aware of the potential sources of information. However, several research centres now serve as repositories of GCM information (e.g. the National Centre of Atmospheric Research, USA; the Climatic Research Unit, UK; the Commonwealth Scientific and Industrial Research Organisation, Australia). Some of these have also developed software for extracting, displaying and comparing information from different GCMs (e.g. see Hulme *et al*., 1995; Jones, 1996). The IPCC Data Distribution Centre complements these existing sources.

Thus, assuming that the user is in a position to select from a large sample, which results should be chosen? Four criteria for selection are suggested in Smith and Hulme (1998): vintage, resolution, validity and representativeness of results.

5.1.1 Vintage

In general, recent model simulations are likely (though by no means certain) to be more reliable than those of an earlier vintage. They are based on recent knowledge, incorporate more processes and feedbacks and are usually of a higher spatial resolution than earlier models. Therefore, it is of some concern that results from equilibrium experiments conducted as long ago as the early 1980s are still widely adopted in impact assessments without reference to more recent experiments. Moreover, one of the problems often encountered in evaluating impact studies is knowing exactly which version of a GCM has provided the scenario information. Part of this is due to poor reporting by the impact analysts, but part can also be attributed to confusing documentation of the model outputs. For instance, there are many sets of results available from different experiments conducted by the same modelling group, and quite often these have been denoted using the same model name or acronym.

5.1.2 Resolution

As climate models have evolved and computing power has increased, there has been a tendency towards increased resolution. Some of the early GCMs operated on a horizontal resolution of some 1000 km with between 2 and 10 levels in the vertical. More recent models are run at nearer 250 km spatial resolution with perhaps 20 vertical levels (more in some ocean models). However, although higher resolution models contain more spatial detail (i.e.

complex topography, better-defined land/sea boundaries, etc.) this does not necessarily guarantee a superior model performance.

5.1.3 Validity

A more persuasive criterion for model selection is to adopt the GCMs that simulate the present-day climate most faithfully, on the premise that these GCMs would also yield the most reliable representation of future climate. Several large impact assessment projects have used this approach (e.g. Smith and Pitts, 1997).

The approach involves comparing GCM simulations that represent present-day conditions with the observed climate. The GCM run is typically the control simulation of an equilibrium GCM experiment, but for transient experiments, the modelled period corresponding to the observed data (e.g. 1961-1990) is adopted. The modelled and observed data are projected to the same grid, and statistical methods employed to compare, for example, mean values, variability and climatic patterns. For instance, a useful measure of similarity between the modelled and observed pattern of climate, which has been widely employed in model intercomparison studies, is the spatial pattern correlation coefficient (e.g. Hulme, 1991; Whetton *et al*., 1996).

However, it should be noted that the relative performance of GCMs can depend critically on the size of the region (i.e. small regions at sub-grid-scale are less likely to be well described than large regions at continental scale), on its location (i.e. the level of agreement between GCM outputs varies a lot from region to region) and on the variables being analysed (for instance, regional precipitation is more variable and more difficult to model than regional temperature). Indeed, rather than searching for the best performing model, perhaps the most valuable function of a model intercomparison study is to exclude those models whose performance is unacceptably poor, especially in estimating features of the climate that are of critical importance for the impact application. Furthermore, it should also be remembered that the models giving the best pattern correlation coefficients for the control simulation may not necessarily be the models providing the most reliable predictions.

Many international model intercomparison projects have been conducted and reported, often focusing on regions that are relevant to impact assessment. Comparison of models with observations is a key component of these projects, and impact assessors are encouraged to consult these before undertaking their own analysis. Most of these projects are ongoing and are well documented on the Internet (see list and links at: http://www-pcmdi.llnl.gov/amip/OINTS/oints.html). They include:

- AMIP - Atmospheric Model Intercomparison Project I (1990-1996) and II (1996-)
- CMIP - The Coupled Model Intercomparison Project
- ENSIP - ENSO (El Niño/Southern Oscillation) Intercomparison Project
- GRIPS - GCM-Reality Intercomparison Project for SPARC (Stratospheric Processes And their Role in Climate)
- PILPS - Project for Intercomparison of Landsurface Parameterization Schemes
- PIRCS - Project to Intercompare Regional Climate Simulations
- SIMIP - Sea-ice Model Intercomparison Project
- SMIP - Seasonal Model Intercomparison Project
- STOIC - Study of Tropical Oceans in Coupled Models

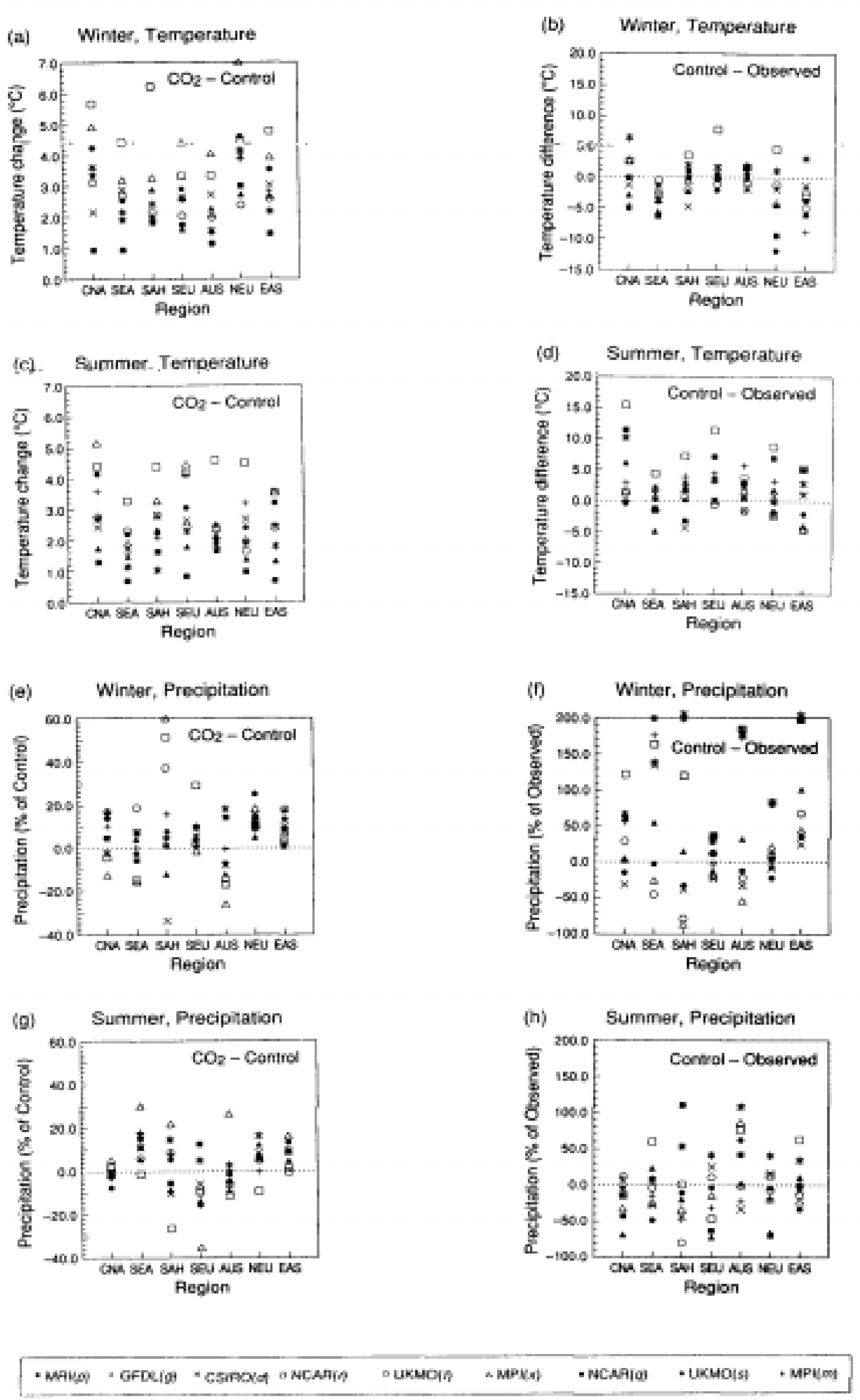


Figure 5.1 Differences between averages at time of CO_2 doubling and control run averages (CO_2 - Control) and difference between control run averages and observed averages (Control - Observed) as simulated by nine AOGCM runs over seven regions. CNA = Central North America, SEA = South East Asia, SAH = Sahel, SEU = Southern Europe, AUS = Australia, NEU = Northern Europe, EAS = East Asia. Source: Kattenberg *et al*. (1996).

In addition GCM comparisons for seven world regions: central North America, south-east Asia, the Sahel region in Africa, southern Europe, Australia, northern Europe and east Asia were reviewed by the IPCC in its Second Assessment Report (Kattenberg *et al*., 1996) and the results are summarised in Figure 5.1 taken from that report.

The scope for selection has been increased with the advent of ensemble experiments, which assume an identical radiative forcing but slightly different initial conditions. Since each ensemble experiment is equally plausible, it is important to know how their results compare. In selecting from ensemble members, one option is to average the members to provide a composite ("consensus") climate. However, internal consistency may be compromised through this procedure, so it is advisable to use all ensemble members separately in an impact assessment, if possible.

The Data Distribution Centre has provided graphical and statistical tools to facilitate the intercomparison of information from the seven core AOGCMs (including ensembles) and the observed CRU Global Climate Data Set.

5.1.4 Representativeness of results

If results from more than one GCM are to be applied in an impact assessment (and given the known uncertainties of GCMs, this is strongly recommended), another criterion for selection is to examine the representativeness of the results. Alternative GCMs can display large differences in estimates of regional climate change, especially for variables like precipitation, which frequently show wetter conditions in a region in some models and drying in others.

Where several GCMs are to be selected, it might be prudent, therefore, to choose models that show a range of changes in a key variable in the study region (for example, models showing little change in precipitation, models showing an increase and models showing a decrease). The selections may not necessarily be the best validated models (see above), although some combination of models satisfying both criteria could be agreed upon. For example, a study in southern Africa adopted three GCMs: a core scenarios based on the GCM that, out of a sample of 11 examined, correlated best with the observed climate, and two other scenarios from GCMs that captured the extreme range of regional precipitation changes obtained in the 11 experiments (Hulme, 1996 - see Figure 5.2).

Similar comparisons were presented by Kattenberg *et al*. (1996) for 9 transient experiments at the time of CO_2 doubling (see Figure 5.1). Again, the intercomparison tools provided by the DDC provide an opportunity to assess the representativeness of outputs from the seven core AOGCMs. An intercomparison study of these with other GCM outputs is being undertaken by the DDC for different regions and will be presented in a later version of these Guidelines. The approach is outlined in more detail in Section 5.3.3, below.

A note of caution is required in interpreting a modelled change in climate between the present and future. While conflicting results are commonly reported from different models, it is not always clear that they each represent a genuine greenhouse gas signal. Until recently, most impact assessments relied on GCM outputs based on 10-year averaged climate. Given the substantial inter-decadal climatic variability exhibited by most GCMs, it was often difficult to distinguish a climate change signal from the background noise. For this reason, it is strongly recommended that at least a 30-year period be employed for averaging GCM output data, to dampen the effects of inter-decadal variability. This point is expanded in section 5.3.2.

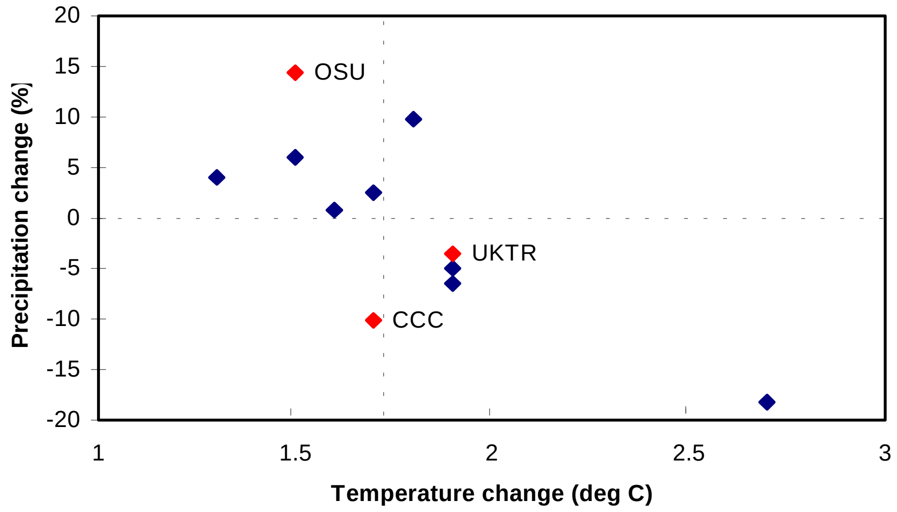


Figure 5.2 Changes in average annual temperature and precipitation for the 2050s relative to 1961-1990 from eleven GCM experiments for a 10° latitude/longitude region of southern Africa centred on Zimbabwe. The three experiments indicated in red were selected as scenarios. Source: Hulme (1996).

5.2 Constructing scenarios

Once GCM outputs have been selected for use in an impact study, there are numerous procedures available for processing and applying the data (i.e. constructing the scenarios). The procedure chosen can itself have a strong influence on the actual climate changes imposed on an exposure unit.

5.2.1 Constructing change fields

GCM outputs are not generally of a sufficient resolution or reliability to be applied directly to represent the present-day climate. Instead, it is usual for baseline observational data to be used, which are commonly in the form of time series of daily or monthly data for several variables over a period such as 1961-1990 (section 2.1).

A scenario of future climate is obtained by adjusting the baseline observations by the difference (or ratio) between period-averaged results for the GCM experiment (usually 10 or 30 year periods are used) and the corresponding averages for the GCM control simulation. In recent transient experiments, the simulated baseline period (e.g. 1961-1990) is used in place of the control-run results. Differences are usually applied for temperature changes (e.g. 2040-2069 minus 1961-1990) while ratios are commonly used for precipitation change (e.g. 2040-2069 divided by 1961-1990), though differences may be preferred in some cases. When this procedure is completed across some or all of the model grid boxes, a pattern of differences or ratios known as a "change field" is produced.

Change fields of 30-year averages for eight variables have been computed from the monthly outputs of all experiments held in the Data Distribution Centre. In this case, changes for all variables are expressed as *differences* relative to the present, where the present refers to model simulated 1961-1990 climate.

5.2.2 Downscaling

One of the major problems in applying GCM projections to regional impact assessments is the coarse spatial scale of the gridded estimates in relation to many of the exposure units being studied. Several methods have been adopted for developing regional GCM-based scenarios at the sub-grid scale, a procedure variously known as “regionalisation” or "downscaling" (see, for example, Giorgi and Mearns, 1991; Wilby and Wigley, 1997).

5.2.2.1 Using original grid box information

The simplest method of applying GCM changes is to use values for the nearest grid box to the study area. There are several drawbacks of this method. First, because of the lack of confidence in regional estimates of climate change, it has been suggested that the minimum effective spatial resolution should be defined by at least four, and probably more GCM grid boxes (e.g. von Storch *et al*., 1993). Second, sites in close proximity but falling in different grid boxes, while having a very similar baseline climate, may be assigned a quite different scenario climate. Third, a site on land may fall within the bounds of a GCM grid box defined (due to its coarse spatial resolution) as ocean (and *vice versa*). The climate response over land grid boxes is known to differ from that over ocean boxes.

5.2.2.2 Interpolating grid box outputs

The simplest method of downscaling is to interpolate the change fields to the site or region of interest from nearby grid boxes (e.g. Harrison *et al*., 1995; Neilson, 1998). This overcomes the problem of discontinuities in changes between adjacent sites in different grid boxes, but it also introduces a false geographical precision to the estimates. Most impact applications consider one or more fixed time horizon(s) in the future (e.g. the 2020s, 2050s and 2080s have been chosen as 30-year time windows for storing change fields in the DDC). Some other applications may require time-dependent information on changes, such as vegetation succession models that simulate transient changes in plant composition (e.g. VEMAP members, 1995).

5.2.2.3 Statistical downscaling

More sophisticated downscaling techniques calculate sub-grid scale changes in climate as a function of larger-scale climate or circulation statistics. Some approaches utilise statistical relationships between large-area and site-specific surface climates (e.g. Wigley *et al*., 1990) or between large-scale upper air data and local surface climate (e.g. Karl *et al*., 1990; Winkler *et al*., 1997; Crane and Hewitson, 1998). Others have examined relationships between atmospheric circulation types and local weather (e.g. Hay *et al*., 1992; Conway *et al*., 1996; Brandsma and Buishand, 1997). When applied to daily GCM data, these techniques can provide daily climate scenarios for specific sites or regions. Statistical downscaling is much less computationally demanding than physical downscaling using numerical models (see section 5.2.2.4), offering an opportunity to produce ensembles of high resolution climate scenarios.

However, they can require large amounts of observational data to establish statistical relationships for the present-day climate, and a high degree of specialist knowledge and skill is needed to apply statistically downscaled results sensibly in impact assessments. Moreover, they are based on a fundamental assumption that the observed statistical relationships will continue to be valid under future radiative forcing, i.e. they are time-invariant. This proposition is questioned by Wilby (1997), who found significant variations in relationships developed for daily precipitation using data from different periods during the past century in the United Kingdom. Another important weakness of circulation based downscaling methods is that the scenarios produced are relatively insensitive to future climate forcing (see Wilby and Wigley, 1997).

5.2.2.4 High resolution experiments

Another method of obtaining more localised estimates of future climate is to conduct experiments with numerical models at high resolution over the region of interest. This can be done in several ways. One method is to run a full GCM at higher resolution for a limited number of years in "time slice" experiments. Another method involves running a GCM at varying resolution across the globe, with the highest resolution over the study region ("stretched grid" experiments). A third method makes use of a separate high resolution limited area model (LAM), using conventional GCM outputs (control simulation and experiment) to provide the boundary conditions for the LAM (the "nesting" approach). There are also examples of "double nesting", in which a fine resolution LAM is nested in a LAM, which has itself first been nested in a GCM (e.g. Whetton *et al*., 1997). Finally, statistical and dynamical downscaling methods can be combined to produce very high resolution climatic scenarios and land-atmosphere feedbacks (e.g. Zhang and Foufoula-Georgiou, 1997).

Regional models have been used to conduct climate change experiments for many regions of the world, including parts of North America, Asia, Europe, Australia and southern Africa. These approaches were reviewed by the IPCC (Kattenberg *et al*., 1996) and an intercomparison project for regional climate simulations (PIRCS) was listed in section 5.1.3.

These methods of obtaining sub-grid scale estimates (sometimes down to 50 km resolution) are able to account for important local forcing factors such as surface type and elevation, which conventional GCMs are unable to resolve. They have the advantage of being physically based, but are also highly demanding of computer time. For this reason, very few simulations have been made for a sufficient period of simulated years to allow meaningful climate change statistics to be extracted. Furthermore, the commonest approach, nesting, is still heavily reliant on specialised GCM outputs for its boundary conditions - the GCMs do not always provide good simulations of the large scale flow and there can be inconsistencies between the behaviour of the physical parameterisations in the driving model and in the finer grid of the regional model.

Nonetheless, the situation is changing rapidly, and a number of long-period simulations with LAMs for a few regions of the world, which overcome some of the problems described above, will soon be available for use in impact assessment. Indeed, there are examples of impact studies that have already made use of such information (e.g. Mearns *et al*., 1997). Although outputs from LAM experiments are not being made available from the DDC, they can be obtained by contacting the respective modelling groups.

5.3 Interpreting GCM results and their uncertainties

5.3.1 Sources of uncertainty

Model intercomparison studies, such as those presented above, provide valuable information on the differences between GCM projections and the reasons for these differences. However, the range of GCM results is unlikely to be indicative of the full range of uncertainties about future climate. Three main sources of uncertainty can be identified:

1. Uncertainties in future greenhouse gas and aerosol emissions. The IS92 and provisional SRES emissions scenarios described in Section 4 exemplify these uncertainties, with each scenario implying different levels of atmospheric composition and hence of radiative forcing.

2. Uncertainties in global climate sensitivity (cf. Section 3.2), due to differences in the way physical processes and feedbacks are simulated in different models. This means that some GCMs simulate greater mean global warming per unit of radiative forcing than others.

3. Uncertainties in regional climate changes, which are apparent from the differences in regional estimates of climate change by different GCMs for the same mean global warming (see, for example, Figure 5.2).

While the results of GCM experiments probably capture a large part of the uncertainty ranges in 2 and 3, they certainly do not encapsulate the range of emissions described in 1. Due to constraints of time and resources, only a limited number of GCM experiments can be conducted. In addition, many experiments have been specifically designed to be directly comparable with other models, to aid model development, and their assumed forcing is very similar. Most early GCM experiments were for a hypothetical 2 x CO_2 equilibrium case. The AOGCM outputs in the DDC are for transient forcing approximating to a 1% increase in equivalent CO_2 per year (close to the IS92a emissions scenario). One set of runs for an IS92d emissions scenario (approximately a 0.5%/year increase) is also included from the HadCM2 model. Some alternative emissions scenarios have also been used in experiments with the GFDL model (assuming 0.25%, 0.5%, 1%, 2%, and 4%/year increases - Kattenberg *et al*., 1996), but these are not included in the DDC.

An alternative approach for estimating the effects of emissions uncertainties on climate is to use simple models. These enable the user to explore, very rapidly, the consequences for global mean temperature of large numbers of possible emissions scenarios. The approach is described in more detail in Box 4.

5.3.2 A combined approach to represent uncertainty

A combined approach, using information both from simple models and from GCMs, offers the possibility to represent the three types of uncertainty described above. In this approach, the *magnitude* and *timing* of global mean temperature change are supplied by the simple model, on the basis of a given emissions scenario, and the regional *pattern* of change in temperature and other climatic variables is supplied by a GCM. The approach comprises three stages (Smith and Hulme, 1998):

1. The standardised pattern of climate change from the GCM is estimated by dividing individual grid box changes by the global mean warming of that model experiment, yielding a ratio. Changes are computed between the present and future climate as simulated by the GCM. For instance, this might be the change between 10 year periods of the control run and the 2 x CO_2 run in an equilibrium experiment, or between the model simulated 1961-1990 and 2040-2069 (centred on 2055) periods of a transient experiment.

2. The magnitude of global warming by a specified date in the future is estimated from the simple model for a given emissions scenario and a given climate sensitivity.

3. The patterns of changes in different climatic variables (i.e. the ratios computed in stage 1) are multiplied by the global warming value from stage 2 in a procedure known as "scaling".

BOX 4 USING SIMPLE MODELS TO ESTIMATE GLOBAL MEAN TEMPERATURE AND SEA-LEVEL CHANGE

GCMs are the most comprehensive tools for estimating the response of climate to radiative forcing. However, they are also computationally and resource intensive, with a single experiment typically requiring several person-years to design, run, analyse and release. Moreover, one experiment provides information, albeit detailed, on only one possible scenario of the future.

An alternative method of investigating climate response to radiative forcing is to use simpler models, that generalise many of the processes simulated explicitly by a GCM. A system of simple global models has been used by the IPCC for its 1990 and 1995 assessments to investigate the effects of different emissions scenarios (Wigley and Raper, 1992; IPCC, 1997). It comprises the following components (Figure B4.1):

- Gas models for each of the main greenhouse gases, which convert emissions into atmospheric concentrations and subsequently compute radiative forcing. Values of key parameters of each model can be adjusted across a representative uncertainty range.
- An upwelling diffusion-energy balance (UD/EB) climate model, which computes global mean temperature response to a given radiative forcing. The parameters of the model can be altered to represent uncertainties in GCMs. For example, the climate sensitivity can be selected from a range of values, along with a factor accounting for the differential heating of land and ocean (observed in GCM results). This latter parameter is important for estimating the thermal expansion component of sea-level rise.
- Ice melt and thermal expansion models, which are used to compute sea-level change.

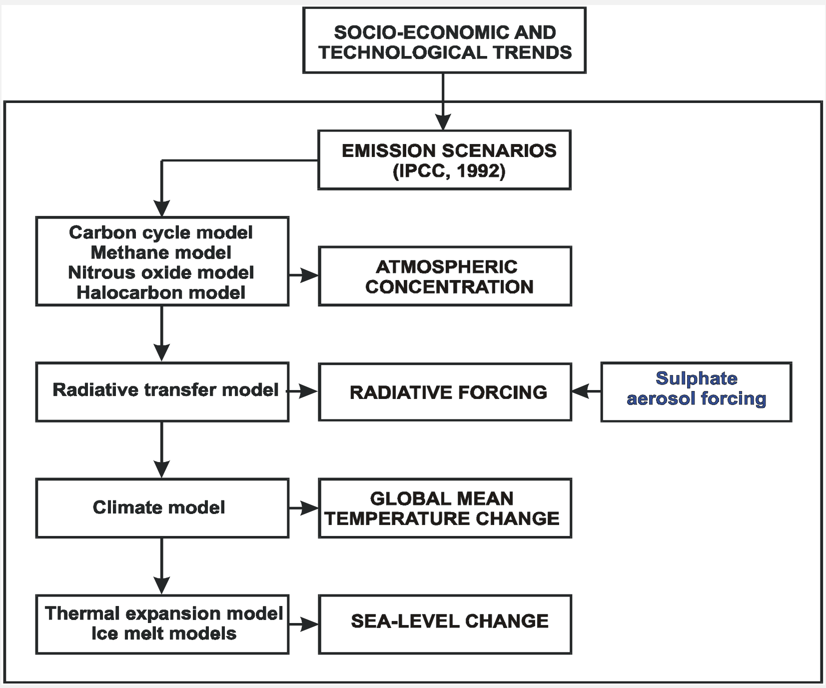


Figure B4.1 Schematic diagram of the simple model system employed by the IPCC. Source: IPCC (1994)

This model system was used to estimate atmospheric concentrations, global temperature changes and sea-level rise for the IS92 and provisional SRES scenarios in Tables 4.1 and 4.2. There are several advantages to be gained by using simple models of this kind:

- They are simple to operate.
- They are computationally fast, and can be used to examine a large number of scenario simulations.
- They produce scenarios of greenhouse gas emissions, atmospheric concentrations, radiative forcing, temperature response and sea-level rise that are physically consistent
- They can provide timely information for policy makers, for instance, enabling comparisons to be made of the effects on climate of alternative measures to limit greenhouse gas emissions.

In this way it is possible to generate regional climate scenarios that combine the uncertainties represented by the emissions scenarios, uncertainties about the climate sensitivity and uncertainties related to the regional pattern of climate change. An example of how this approach can be applied in sensitivity studies is shown in section 5.3.3, below.

A fundamental assumption of the scaling approach is that while the magnitude of climate change alters over time in proportion to the global warming, the pattern of change from the GCM remains constant. This is problematic for two reasons. First, it can be difficult to establish whether the pattern of change represents a climatic response to radiative forcing or is simply an artefact of natural climatic variability. It may take many decades of a transient experiment before the climate change "signal" emerges from the "noise" of year-to-year variability.

A second problem is that regional climate may not respond coherently to increased radiative forcing, and hence the pattern of change may not be constant over time. For instance, it has been shown that the pattern of precipitation change can vary substantially during a transient simulation, sometimes changing sign. However, these results may be related to the high natural variability of precipitation. A pattern correlation analysis to compare an AOGCM experiment assuming 0.5%/year increase in emissions with an experiment assuming a 1%/year increase concluded that the regional pattern of temperature change was fairly similar at different periods during both simulations, while the pattern of precipitation change was much more variable (Mitchell *et al*., 1999). It should also be noted that the assumption of a consistent emerging pattern of change is the basis of recent detection studies that have produced evidence of an anthropogenic "fingerprint" in observations of the climate (Santer *et al*., 1996). Pattern scaling methods are harder to apply in the case of combined greenhouse gas and aerosol climate change fields; in this case, regionally-scaled aerosol patterns may need to be defined and combined with greenhouse gas only patterns (Schlesinger *et al*., 2000).

5.3.3 Guided sensitivity analysis

The use of synthetic scenarios, which are arbitrary adjustments to the baseline climate, was identified in Section 3.3.1 as an alternative to applying GCM-based scenarios. These scenarios can be used to explore the sensitivity of an exposure unit to a range of climatic variations. One way of refining this type of analysis, is to make use of the combined information from GCMs and simple models to define a credible range of plausible changes in regional climate, which can guide sensitivity analysis (Hulme and Brown, 1998).

This idea is illustrated in Figure 5.3 for grid boxes over central India. 14 GCM outputs were standardised to a global mean warming of 1.4°C by 2050, based on a simple model (Box 4) assuming the IS92a emissions scenario and a climate sensitivity of 2.5°C. Their scaled regional estimates are plotted as temperature and precipitation changes relative to the baseline (solid circles). The straight lines represent the range of estimates obtained under extreme combinations of greenhouse gas emissions and climate sensitivity. For example, the largest changes are obtained under a combined scenario of high emissions (IS92e) and high climate sensitivity (+4.5°C); the lowest changes under low emissions (IS92c) and low sensitivity (+1.5°C).

The estimated range of natural variability (±2 standard deviations of 30 year smoothed data) is also shown in Figure 5.3 for comparison with the simulated changes in climate, using both a century of observations (at the origin - open circle) and a 240-year control simulation (± 2 sd either side of the Hadley Centre AOGCM greenhouse gas-only simulation - open square). The Hadley Centre GHG plus aerosols experiment is also shown for comparison (solid square).

The resulting envelope of temperature and precipitation changes embraces much of the current uncertainty in future estimates over central India. In this example, all experiments indicate a warming, in most cases significant relative to natural variability (i.e. the width of the horizontal error bars). In addition, all but two of the GHG-only experiments indicate an increase in precipitation, most of them significant (vertical bars). However, both the Hadley Centre experiments and one other experiment show a decrease in precipitation. Indeed, the aerosols experiment shows the most marked warming and drying of all the 16 models portrayed, in contrast to the finding globally that temperature increases are suppressed by aerosols (Figure 3.4).

One of the criticisms of scenario analyses such as those portrayed in Figure 5.3, which attempt to account for the three types of uncertainty described above, has been that all plausible projections of future climate are implicitly accorded an equal probability of occurrence. Jones (2000a) argues that this assumption is erroneous, and that outcomes at the extremes of the uncertainty range are less probable (on statistical grounds) than outcomes towards the centre of the range.

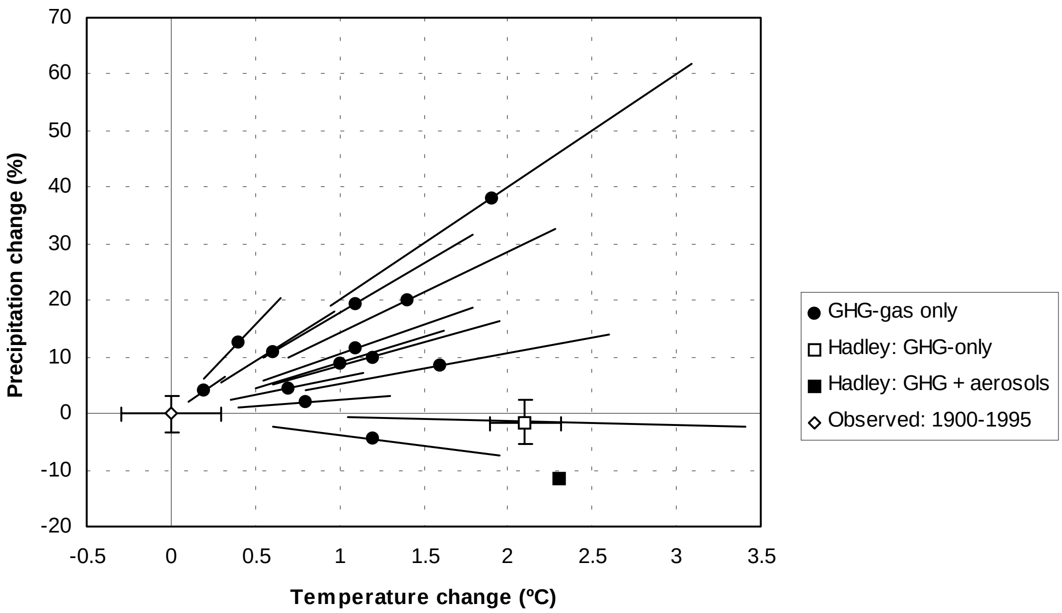
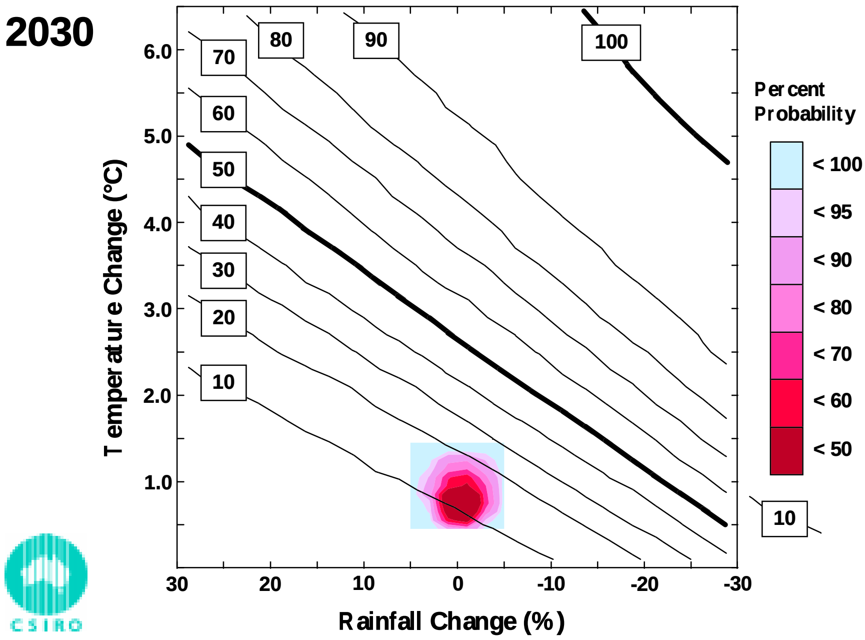


Figure 5.3 Temperature and precipitation change by 2050 relative to 1961-1990 over central India. Source: Parry and Carter (1998), modified from a draft version of Hulme and Brown (1998).

He illustrates this with an example of an impact study which combined a sensitivity analysis (cf. Section 3.3.1) with a probability analysis of the likelihood of various combinations of temperature and precipitation change in Australia based on a combination of simple model and GCM outputs. The objective of the study was to assess the risk of exceeding a threshold demand for annual irrigation (12 $Mlha^{-1}$), which would require an adaptive response. The sensitivity study evaluated the percentage of years in which the threshold is exceeded for arbitrary combinations of changes in temperature and precipitation. Superimposing probability plots of expected climate changes (based on a Monte Carlo analysis of combinations of outcomes across the range of uncertainty) onto the sensitivity graph yielded an estimate of the changing risk of exceeding the irrigation threshold between 1990 and 2100 (Figure 5.4). Further analysis established that, for instance, by 2030 there is only a 5%

probability that the climate will have changed enough to produce an exceedance of the threshold in 20% of years. However, by 2070, the probability of the required climate change occurring has risen to 80%.

(a)



(b)

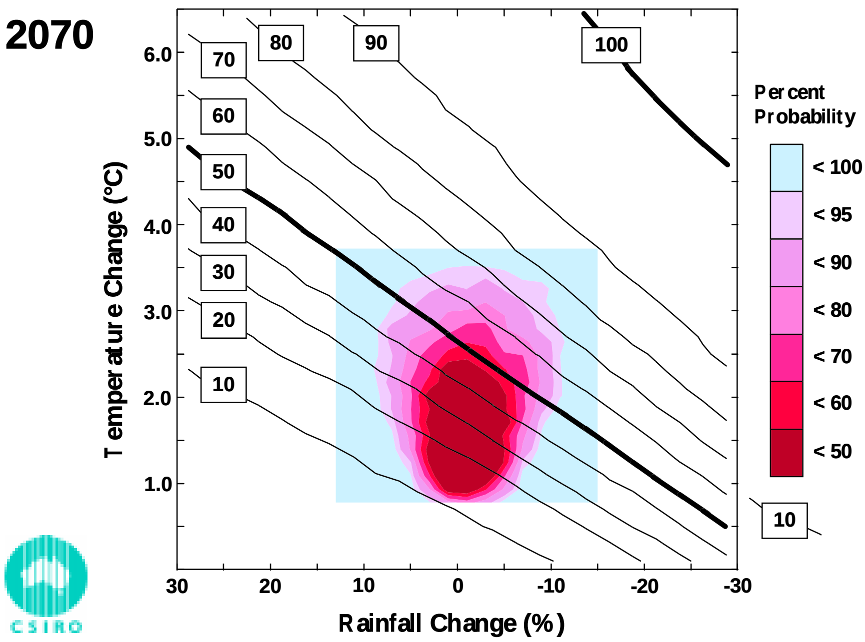


Figure 5.4 Cumulative probability plots for climate scenarios (coloured) and probability of exceedence of an annual irrigation threshold (black lines) for 2030 and 2070 in northern Victoria, Australia. High percentages on the cumulative probability scale indicate a low probability of obtaining a given combination of temperature and precipitation change (e.g. <100 represents an occurrence probability of between 0 and 5%). Source: Jones (2000b).

5.4 Changes of means and variability

Outputs from GCMs are usually applied as monthly or seasonal adjustments to the baseline climate in impact assessments, assuming no change in climatic variability between the baseline and future climate. Thus the pattern of diurnal, day-to-day and inter-annual variability of climate remains unchanged (unless inadvertent adjustments are made to the baseline climatic variability - see section 5.4.5, below). However, sensitivity studies that altered the variability of climate across a plausible range have demonstrated that changes in climatic variability can be just as important for an exposure unit, if not more so, than changes in the mean climate (e.g. Katz and Brown, 1992; Semenov and Porter, 1995). So what do GCMs tell us about future climatic variability?

Unfortunately, there is still great uncertainty about GCM estimates of future climatic variability. Some of the key issues are discussed in Kattenberg *et al*. (1996) and a few are summarised below.

5.4.1 Interannual variability

Perhaps the most important source of interannual variability in the tropics and beyond is the ENSO phenomenon. However, it is not clear whether ENSO events will change character as a response to global warming, though recent simulations with the ECHAM4 GCM indicated an increase in the frequency of ENSO events (Timmermann *et al.*, 1999) and there is a suggestion from other model results that precipitation variability associated with ENSO events may be enhanced, especially over tropical continents (Trenberth and Hoar, 1997). There is also growing evidence that interannual temperature variability may decrease in northern mid-latitudes in winter.

5.4.2 Severe storms and cyclones

There is little agreement between GCMs about possible changes in the frequency, intensity and track of mid latitude storms under climatic warming (Kattenberg *et al.*, 1996). The situation is similar regarding future changes in tropical typhoons, although a recent study coupling GCM outputs with a high resolution forecast model in the western Pacific simulates an increase of storm intensity for a doubling of CO_2 (Knutson *et al*., 1998).

5.4.3 Precipitation variability

There is more evidence to suggest that precipitation variability may change in the future. The hydrological cycle is likely to be more intense under a warmer climate and several models have shown an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events (e.g. Fowler and Hennessy, 1995). At the same time, some models also project more frequent or severe drought periods over land areas.

5.4.4 Diurnal temperature range

Mean monthly minimum temperatures are known to have increased by about twice as much as mean monthly maximum temperatures worldwide since 1950 (Karl *et al*., 1991; Horton, 1995). This narrowing of the diurnal temperature range (DTR) can be of importance for some exposure units (e.g. crop plants - Williams *et al*., 1988). Since most GCMs, including all of those held at the Data Distribution Centre, provide information on both temperature variables, impact analysts have an opportunity to examine whether this decrease in the DTR (observed in most but not all regions) is projected to continue into the future. There have also been some initial attempts to construct statistically downscaled scenarios of DTR (e.g. Kaas and Frich, 1995).

5.4.5 Scenarios of changing variability

A number of recent impact studies have used stochastic weather generators (Box 1) or other synthetic methods to develop scenarios combining mean changes with variability changes on the basis of GCM or regional model outputs (e.g. Wilks, 1992; Mearns *et al*., 1997; Semenov and Barrow, 1997). These have focused primarily on changes in daily variability, though some studies have also considered inter-annual variability (e.g. Mearns *et al*., 1996). It should be noted that inadvertent adjustments to the daily variability of certain variables can occur through apparently straightforward mean adjustments of daily baseline observations (e.g. Mearns et al., 1997 have demonstrated this when adjusting baseline precipitation according to monthly mean ratios of GCM-derived 2 x CO_2/control precipitation changes).

5.5 Applying non-climatic scenarios

One of the key criteria in selecting a climate scenario was that it should be physically plausible (criterion 2, section 3.2). This criterion also applies to the relationship between climate and non-climatic scenarios. Thus, projections of climate should be consistent both with projections of atmospheric composition and the emissions scenarios upon which they are based, as well as with "downstream" projections of sea-level rise. One way of ensuring this is to use simple models such as those described in Box 4.

Carbon dioxide concentration is one of the most important of the non-climatic factors to consider. Besides being a major greenhouse gas that influences the climate, it is also of great importance for plant growth and productivity. Thus, it is important that appropriate levels of CO_2 concentration are used in conjunction with a given climate change (see, for example, Tables 4.1 and 4.2). Unfortunately, this has been a source of some confusion in past impact studies, especially with regard to the timing of CO_2 doubling. The following points are worth noting:

- Equilibrium GCM 2 x CO_2 experiments commonly assume a radiative forcing equivalent to a doubling of CO_2 concentration (for example from 300 ppmv to 600 ppmv). In fact the absolute concentrations are not especially important, as the temperature response to increasing CO_2 concentration is logarithmic (Shine *et al*., 1990) - a doubling from 500 to 1000 ppmv would have approximately the same climatic effect.
- Equilibrium 2 x CO_2 experiments are usually interpreted as representing an equivalent 2 x CO_2 atmosphere, in which the combined effects of CO_2 and other greenhouse gases on the earth's radiation balance are equivalent to the effect of doubling CO_2 alone. This equivalent doubling is expected to occur several decades before an actual CO_2 doubling.
- The climate has a lag time of several decades in its response to an equivalent CO_2 doubling, as represented in transient AOGCM experiments. Thus, at the time of equivalent doubling, the climate will not have realised its full, equilibrium response to the forcing.
- In CO_2 enrichment experiments with plants, a doubled CO_2 environment relative to ambient is typically imposed (levels of 660 ppmv or 700 ppmv are popularly adopted). In contrast to GCMs, the absolute CO_2 concentration is of importance to plants, because their response to CO_2 is commonly non-linear.

Similarly, relative sea-level rise is predominantly a result of global warming, so this should also be consistent with the estimates of climate change (see section 4.3.2).

***Summary - applying scenarios in impact assessment**: Differences in methods used to select, interpret and apply projections in an impact assessment can influence the results of the study as much as differences between the projections themselves. Four criteria are suggested for selecting GCM-based climate scenarios, related to their vintage, resolution, validity and representativeness. There are also many techniques available for downscaling GCM information to the region of interest, for discriminating between mean changes and changes in climatic variability and for ensuring consistency between climate change and non-climatic scenarios. Nevertheless, whatever scenario choices are made, it is very important to relate these to the known uncertainties in projections. One method of achieving this is through guided sensitivity analysis.*

6 REPORTING STANDARDS

In this section suggestions are put forward concerning the presentation and reporting of impact assessments, especially concerning the use of scenarios. Adherence to some of these basic guidelines will greatly assist the reviewing and synthesis of impact studies for the Third Assessment Report and beyond.

6.1 Appropriate citation of sources

Out of courtesy to the scientists involved, the original sources of the baseline data and scenarios used should be cited correctly. For example, although the Data Distribution Centre will be providing data from AOGCMs, the correct sources to cite in referring to these models are publications by the modelling groups themselves, not the DDC or these Guidelines. The DDC has documented each of the models, so the relevant information is readily available. Similarly, the sources of non-climatic 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). Again, the DDC provides guidance on these.

6.2 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 in circulation, so it is important to identify models using an accepted acronym. Again, the DDC will provide guidance on these.

6.3 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.

6.4 Presentation of results

Impact studies that employ 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 observations or control simulation. Similarly, the impacts of these scenarios should be contrasted with the impacts of natural variability.

6.5 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.

Summary - reporting standards: *Impacts researchers make extensive use of information provided by scientists in the climate modelling and emissions scenario communities. It is therefore important that the information is applied and interpreted appropriately and the sources cited correctly.*

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Appendix 1 IPCC Task Group on Scenarios for Climate Impact Assessment

The Task Group on Scenarios for Climate Impact Assessment (TGCIA) has the following terms of reference:

- To facilitate co-operation between the modelling and impacts communities particularly addressing issues relating to availability and accessibility of model data
- To carry out specific actions from the IPCC Workshop on Regional Climate Change Projections for Impact Assessment listed below:

(i) To undertake and disseminate an inventory of existing or planned studies from AOGCM centres, including the availability and accessibility of the data

(ii) To undertake and disseminate an inventory of existing or planned studies from regional modelling centres, including the availability and accessibility of the data.

(iii) To consider the requirement for, and possible contents of, a standard set of climate projections for use in impact assessment

(iv) To consider recommending particular regions for regional model intercomparison studies.

(v) To consider recommending time windows for particular study using time slice experiments

(vi) To consider producing guidance material on the use of climate projections in impact assessment

(vii) To consider, in the light of results showing how well energy balance models replicate global mean changes in GCMs, the requirement for AOGCM centres to carry out one or two stabilisation projections.

The first full meeting of the TGCIA took place in May 1997. The members of the Task Group are drawn from the climate modelling, impacts and emission scenario communities as well as those working at the interface between the various communities (Table A1). It is supported by the Technical Support Units (TSUs) of Working Groups I and II.

Two inventories of climate model studies (actions (i) and (ii)) and an additional inventory of impact studies have been prepared by the TSUs and are freely available. To address action (iii), the Task Group recommended the establishment of a Data Distribution Centre, the preparation of supporting guidance material (this document) and the development of a training programme in the use of scenarios. The training component and the other actions listed above are currently (December 1999) under discussion by the Task Group.

Table A1 IPCC Task Group on Scenarios for Climate Impact Assessment (TGCIA)

Name	Country
Prof. Martin Parry	UK (Chair)
Dr. Jose Daniel Pabon Caicedo	Columbia
Dr. Timothy Carter	Finland
Dr. Ulrich Cubasch	Germany
Dr. Xiaosu Dai	P.R. China
Dr. Paul Desanker	USA
Prof. Mohamed El-Raey	Egypt
Dr. Filippo Giorgi	USA
Dr. David Griggs*	UK
Dr. Mike Hulme	UK
Dr. Murari Lal	India
Dr. Luis Jose Mata	Venezuela
Dr. Linda Mearns	USA
Dr. John Mitchell	UK
Dr. Tsuneyuki Morita	Japan
Dr. Neil Leary**	USA
Dr. Daniel Murdiyarso	Indonesia
Dr. Nguyen Hoang Nghia	Vietnam
Dr. Carlos A Nobre	Brazil
Dr. Maria Noguer*	UK
Dr. Hugh Pitcher	USA
Dr. Cynthia Rosenzweig	USA
Dr. Robert Scholes	South Africa
Dr. Peter Whetton	Australia

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** Working Group II Technical Support Unit (Dr. Richard Moss until 1998)