The Hadley Centre regional climate modelling system

PRECIS — Update 2002

Providing Regional Climates for Impacts Studies

defra
Department for Environment Food and Rural Affairs

DFID Department for International Development

UNDP

Met Office

Summary

- *The Met Office's Hadley Centre for Climate Prediction and Research has developed a regional climate model that can be run on a PC and can be applied easily to any area of the globe to generate detailed climate-change predictions. The intention is to make this modelling system, PRECIS (Providing Regional Climates for Impacts Studies), freely available to groups of developing countries so that they can develop climate-change scenarios at national centres of expertise. As part of this activity, they can use local data to assess model performance in their region, and hence confidence in predictions.*

- *Regional climate models have a much higher resolution than global climate models and, as a result, provide climate information with finer detail, including generally more realistic, local extreme events. Thus regional climate models have the potential to produce substantially improved assessments of a country's vulnerability to climate change and how it can adapt.*

- *The quality of regional predictions is limited by the uncertainties in the global models that drive them. PRECIS will be supplied to users together with a training course which will explain not only the uses and advantages of the model, but also its limitations. They will be encouraged to use PRECIS as one of a number of tools for the development of scenarios, including global models.*

- *The PRECIS regional climate model is already being used to generate scenarios for India, China and southern Africa.*

Funding acknowledgements

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1 Introduction

All parties to the UN Framework Convention on Climate Change (UNFCCC) have a requirement, under Articles 4.1 and 4.8, to assess their national vulnerability to climate change. They are also required to submit National Communications, which include discussion of these vulnerabilities and how they are planning to adapt. It is important that developing countries have their own capacity to do this. Assessment of vulnerability requires an estimate of the impacts of climate change, which in turn is based on scenarios of future climate.

Scenarios are plausible future states of the climate system. They are generally derived from predictions of climate change from global climate models (GCMs) based on emission projections; indeed, in most cases the scenario is the climate-model prediction. Because predictions are uncertain for several reasons, it is advisable to develop a number of possible scenarios of future climate at any location.

GCMs can provide predictions of changes in climate down to scales of a few hundred kilometres or so at best. These predictions may be adequate where the terrain is reasonably flat and uniform, and away from coasts. However, in areas where coasts and mountains have a significant effect on weather (and this will be true for most parts of the world), scenarios based on global models will fail to capture the local detail needed for impacts assessments at a national and regional level. Also, at such coarse resolutions, extreme events such as cyclones or heavy rainfall are either not captured or their intensity is unrealistically low. The best method for adding this detail to global predictions is to use a regional climate model (RCM).

This brochure describes regional climate models and the advantages that they have over global models for providing scenarios of future climate change. It then describes PRECIS, the Hadley Centre regional climate modelling system. PRECIS runs on a PC and comprises an RCM which can be located over any area of the globe, simple interfaces to allow the user to set up and run the RCM, and software (still being developed) to allow display and processing of RCM output. This is followed by sections on the current limitations on the use of RCMs and work planned to overcome these. Finally, three case studies are presented demonstrating the use of the RCM and the climate scenarios it provides.

2 Predictions of future climate change

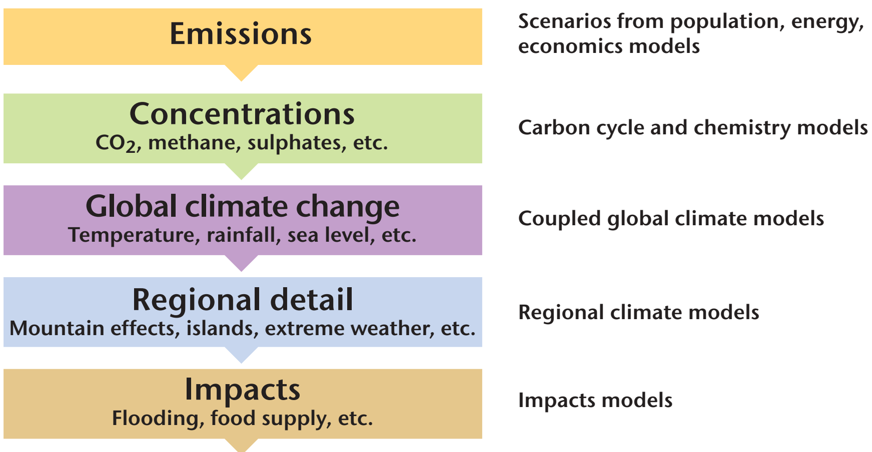
In order to predict future climate change, we first need a projection of how anthropogenic emissions of the greenhouse gases (and other constituents) will change in the future. A range of emissions scenarios has been developed in the IPCC Special Report on Emissions Scenarios (SRES) and reflects a number of different ways in which the world might develop ('storylines') and the consequences for population, economic growth, energy use and technology.

To calculate the effect that these emissions have on the global climate, we employ GCMs. They are comprehensive mathematical descriptions of the important physical elements and processes in the atmosphere, oceans and land surface which comprise the climate system (e.g. winds and ocean currents, clouds, rainfall, soils).

As a result, GCMs are able to simulate the processes and interactions which define the climate of a region. They represent the broad features of current climate well and can reproduce the observed large-scale changes in climate over the recent past, so can be used with some confidence to give predictions of the response of climate to man's current and future activities.

GCMs make predictions at a relatively coarse scale of a few hundred kilometres, but to study the impacts of climate change, we need to predict changes on much smaller scales.

Predicting impacts of climate change



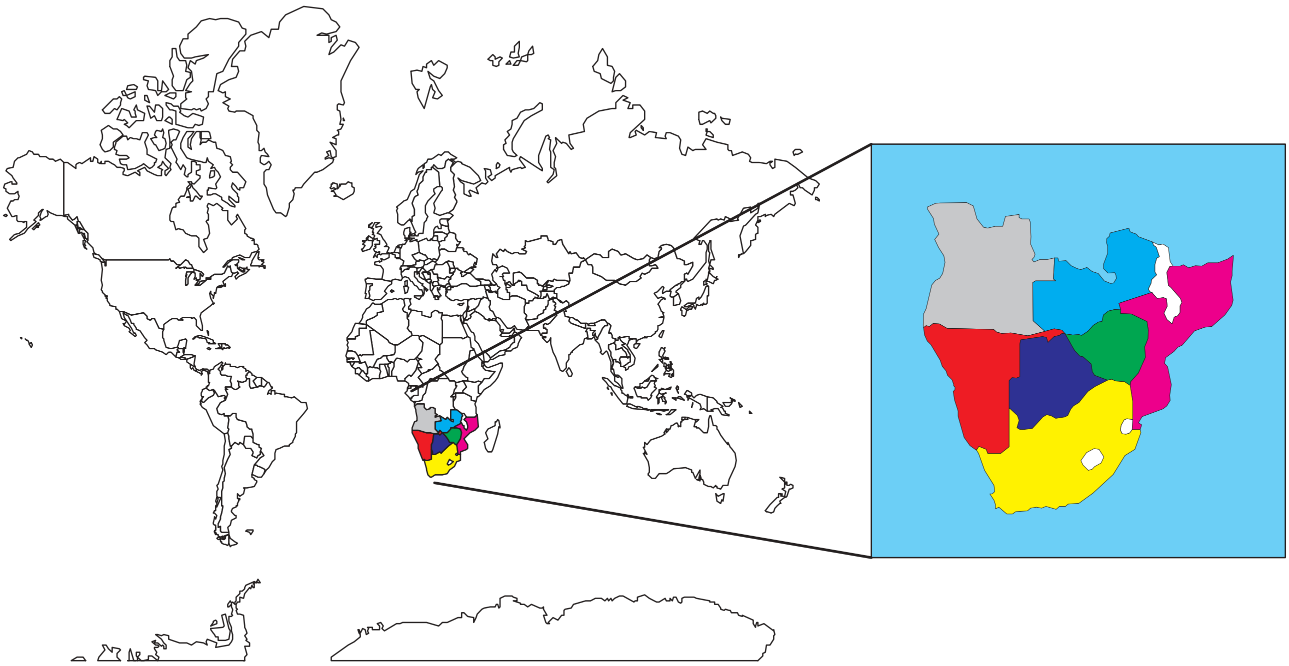
The main stages required to provide climate-change scenarios for assessing the impacts of climate change.

How can we get climate-change information on a smaller scale?

In order to provide predictions at the small scale needed to estimate many of the potential impacts of climate change, we need to add detail to the coarse-scale climate information provided by GCMs, and several ways of doing this have been used in the past. Interpolating between GCM grid points adds no useful information and can be misleading. Similarly a simulated future climate obtained by adding coarse-scale changes from a GCM to high-resolution observations will not contain detailed prediction of future climate.

One method of adding fine-scale information is statistical downscaling. This technique uses observations in today's climate to derive relationships between large-scale climate variables (e.g. surface pressure and atmospheric temperature), and the surface climate at point locations (e.g. precipitation measured by a rain gauge). This relationship is then applied to the GCM simulation of present-day large-scale climate, and prediction of future climate, in order to obtain the change in the local-scale variable of interest. However, we cannot assume that relationships developed in the climate of the recent past will be applicable to the altered climate of the future.

The most proven method for obtaining detailed predictions, which the Hadley Centre has helped to pioneer, is to use a regional climate model, essentially a higher-resolution version of a GCM covering a limited area of the globe. This is driven by large-scale predictions from the GCM to provide high-resolution simulations for a particular area of interest.



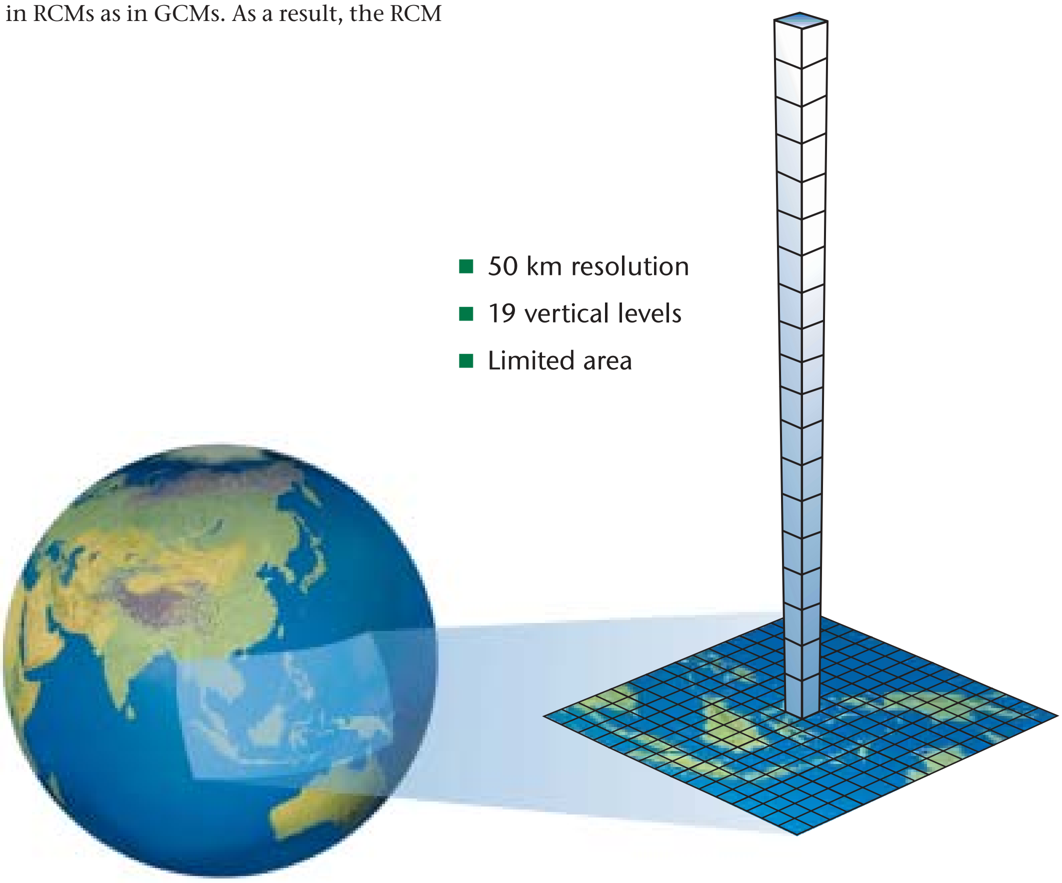
Schematic representation of countries included in a typical domain of a regional climate model.

3 What is a regional climate model?

A regional climate model (RCM) has a high resolution (typically 50 km, compared to 300 km in a GCM; see diagram below) and covers a limited area of the globe (typically 5,000 km x 5,000 km; roughly the size of a box around Australia). It is a comprehensive physical model, usually of the atmosphere and land surface, containing representations of the important processes in the climate system (e.g. clouds, radiation, rainfall, soil hydrology) as are found in a GCM. An RCM does not generally include an ocean component; this would increase complexity and need more computing power; in any case, most applications for impacts assessments require only land-surface or atmospheric data. At its boundaries, an RCM is driven by atmospheric winds, temperatures and humidity output from a GCM. RCM predictions of ideally 30 years (e.g. the period 2071–2100) are needed to provide robust climate statistics, e.g. distributions of daily rainfall or intraseasonal variability.

The Hadley Centre uses the same formulation of the climate system in RCMs as in GCMs. As a result, the RCM provides high-resolution climate-change predictions for a region generally consistent with the continental-scale climate changes predicted in the GCM.

The third-generation Hadley Centre RCM (HadRM3) is based on the latest GCM, HadCM3. It has a horizontal resolution of 50 km with 19 levels in the atmosphere (from the surface to 30 km in the stratosphere) and four levels in the soil. In addition to a comprehensive representation of the physical processes in the atmosphere and land surface, it also includes the sulphur cycle. This enables it to estimate the concentration of sulphate aerosol particles produced from SO_2 emissions. These have a cooling effect as they scatter back sunlight and also produce brighter clouds by allowing smaller water droplets to form. The IPCC SRES emission scenarios show substantial changes in SO_2 emissions in the future, so it is important that the RCM can calculate their effect.

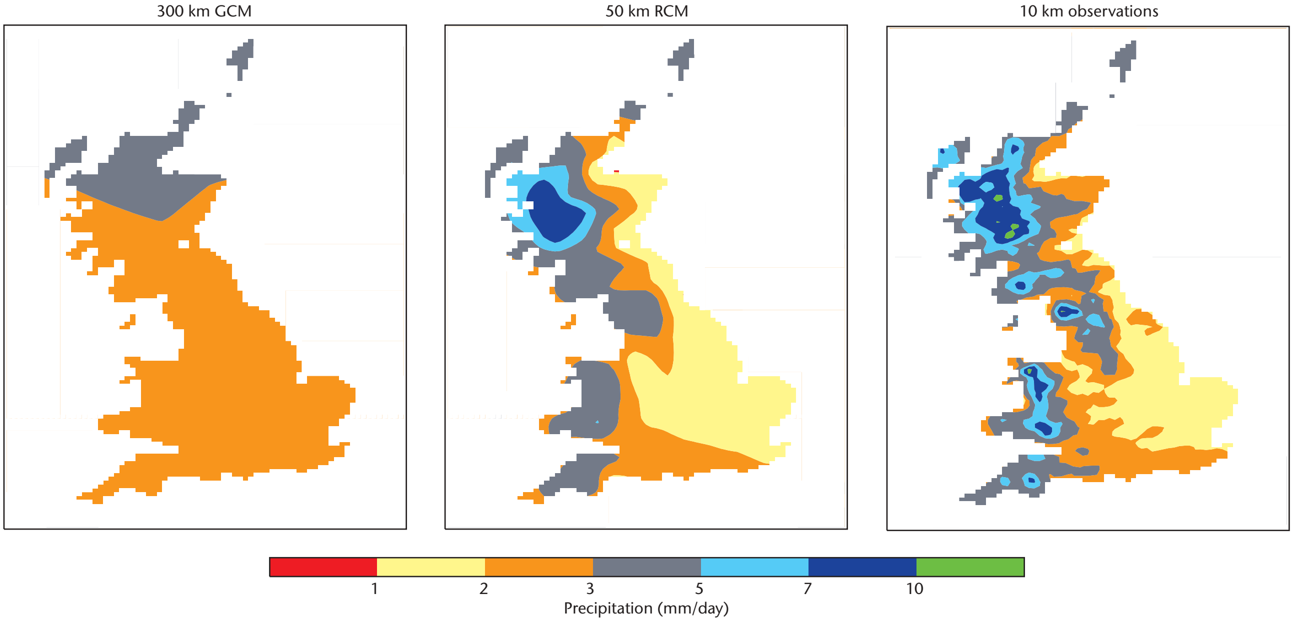


Schematic diagram of the resolution of the Earth's surface and the atmosphere in the Hadley Centre regional climate model.

4 What are the advantages of a regional climate model?

4a RCMs simulate current climate more realistically

Where terrain is flat for thousands of kilometres and away from coasts, the coarse resolution of a GCM may not matter. However, most land areas have mountains, coastlines, etc., on scales of a hundred kilometres or less, and RCMs can take account of the effects of much smaller-scale terrain than GCMs. The diagram below shows simulated and observed precipitation over Great Britain. The observations clearly show enhanced rainfall over the mountains of the western part of the country, particularly the north-west. This is missing from the GCM simulation, which shows only a broad north–south difference. In contrast to the GCM, the 50 km RCM represents the observed rainfall pattern much more closely.

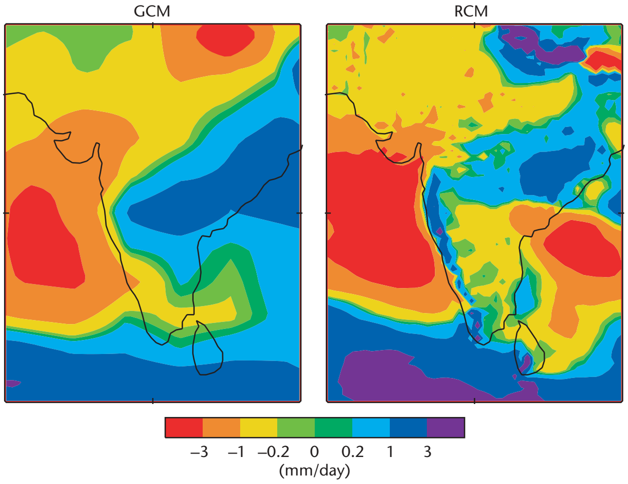


Patterns of present-day winter precipitation over Great Britain. Left, as simulated with the global model. Middle, as simulated with the 50 km regional model. Right, as observed.

4b RCMs predict climate change with more detail and with regional differences

The finer spatial scale will also be apparent, of course, in predictions. When warming from increased greenhouse gases changes patterns of wind flow over a region, then the way mountains and other local features interact with this will also change. This will affect the amount of rainfall and the location of windward rainy areas and downwind rain-shadow areas. For many mountains and even mountain ranges, such changes will not be seen in the global model, but the finer resolution of the RCM will resolve them. The diagram at the top of the next page shows RCM and GCM predicted changes in mean south Asian monsoon rainfall by the middle of the century. These are broadly similar, but there are substantial regional differences.

For example, over much of the Western Ghats mountain range (which runs up the west coast of India) and in parts of southern India, the global model predicts a decrease in rainfall whereas the local effect seen in the RCM is actually an increase. Conversely, over a large area of central India, the RCM predicts decreases, most markedly over the east coast, where the GCM indicates increases. As the RCM better represents the influence of the topography, we have more confidence in its predictions of these regional changes.

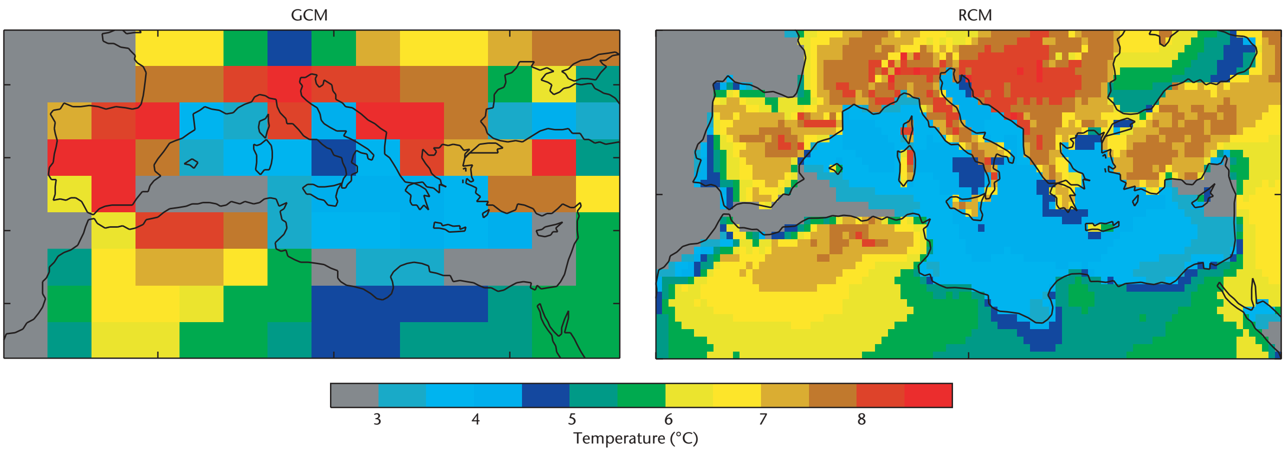


Predicted changes in monsoon rainfall (mm/day) over India, between the present day and the middle of the 21st century from the GCM (left) and from the RCM (right). (The RCM was developed in collaboration with the Indian Institute of Technology.)

4c RCMs represent smaller islands

The coarse resolution of a GCM means than many islands are just not represented and hence their climate is predicted to change in exactly the same way as surrounding oceans. However, the land surface has a much lower thermal inertia than the oceans so will warm faster. If it has any significant hills or mountains, these will have a substantial influence on rainfall patterns. In an RCM, many more islands are resolved, and the changes predicted can be very different to those over the nearby ocean.

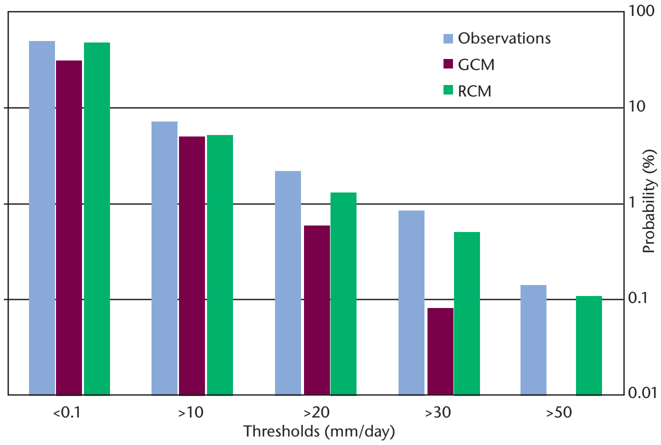
As an example, the diagram below shows the Hadley Centre GCM prediction of summer temperature change in and around the Mediterranean. Even large islands such as Corsica, Sardinia and Sicily are not seen by the GCM, and hence they appear to warm at the same rate as the sea. In contrast, in the corresponding RCM simulation these islands are resolved and are seen to warm faster than the surrounding ocean, as might be expected. Hence, impacts based on the GCM will be in error. (Of course, some islands will not even be resolved at a resolution of 50 km, and await the use of the RCM at a higher resolution.)



Predicted changes in summer surface air temperatures between the present day and the end of the 21st century. Left, from the global model. Right, from the regional model.

4d RCMs are much better at simulating and predicting changes to extremes of weather

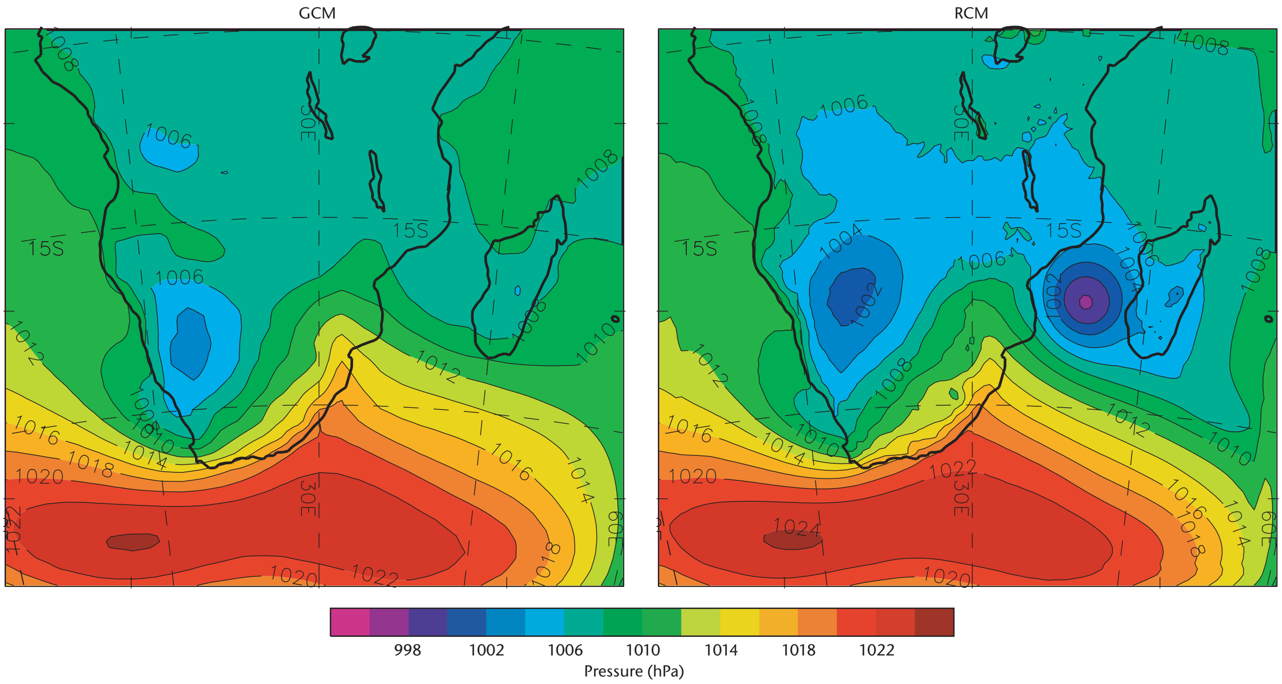
Changes in extremes of weather, for example heavy rainfall events, are likely to have more of an impact than changes in annual or seasonal means. RCMs are much better than GCMs at simulating extremes. The diagram to the right shows the probability of daily rainfall over the Alps being greater than a number of thresholds up to 50 mm. It is clear that the GCM-simulated probability does not agree well with observations, whereas the RCM simulation is much more realistic. For this reason, RCM predictions of changes in extremes in the future are likely to be very different to, and much more credible than, those from GCMs.



The frequency of winter days over the Alps with different daily rainfall thresholds. Blue bars, observed. Red bars, simulated by the GCM. Green bars, simulated by the RCM.

4e RCMs can simulate cyclones and hurricanes

The impact of a hurricane (severe tropical cyclone, typhoon), such as Hurricane Mitch that hit Central America in October 1998, can be catastrophic. We do not know if hurricanes will become more or less frequent as global warming accelerates, although there are indications that they could become more severe. The few hundred kilometre resolution of GCMs does not allow them to properly represent hurricanes, whereas RCMs, with their higher resolution, can represent such mesoscale weather features. This is clearly illustrated below, where the pressure pattern for a particular day simulated by a GCM and that simulated by the corresponding RCM are shown. At first glance, the two pressure patterns look very similar, but a closer examination shows one crucial difference; there is a cyclone in the Mozambique Channel in the RCM which is absent in the driving GCM.



A tropical cyclone is evident in the mean sea-level pressure field from the RCM (right) but not in the driving GCM (left) for the corresponding day (from an RCM over southern Africa, developed by the Hadley Centre in collaboration with the University of Cape Town).

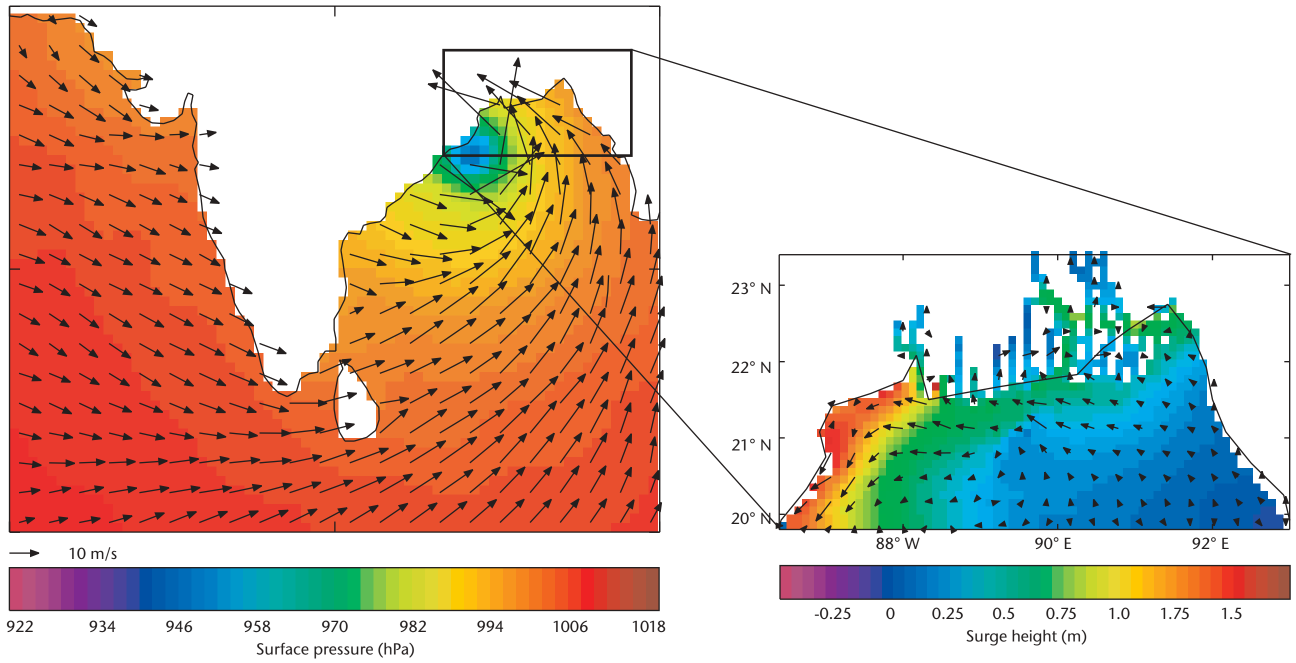
4f RCM data can be used to drive other models

In many cases, output from a climate model is used to drive other models, such as those simulating coastal flooding by short-lived extreme sea-level events, known as storm surges. Although GCM data can be used for this, the resolution is insufficient to provide realistic simulations. The higher resolution of the RCM allows it to drive such a model, which can predict how the frequency and intensity of storm surges might change.

As an example, the RCM simulation of a cyclone in the Bay of Bengal is shown below, together with the corresponding storm surge in the Ganges delta, modelled using RCM data.

As previously mentioned, GCMs do not simulate severe tropical cyclones, and hence would fail to simulate the corresponding storm surges.

Of course, changes in high-water events, which could lead to coastal flooding, will also be strongly influenced by sea-level rise. This is not predicted by the RCM, and therefore comes from GCM predictions. While we have confidence in the global mean predictions of sea-level rise, and can use them in impacts studies, we currently have much less confidence in the regional details.



A cyclone in the Bay of Bengal simulated by the Hadley Centre RCM and the resulting high water levels in the Bay of Bengal. The latter were simulated using a coastal shelf model developed by Proudman Oceanographic Laboratory.

5 PRECIS – Providing Regional Climates for Impacts Studies

There is a growing demand from many countries for regional-scale climate predictions. Yet at present, developing, setting up and using a regional model over a specific area of the globe requires a considerable amount of effort from an experienced climate modeller. In addition, RCMs (like GCMs) are usually run on large computing installations, such as the Cray T3E at the Met Office in the UK. Both these factors effectively exclude many developing countries from producing climate-change predictions and scenarios. The Hadley Centre has developed an efficient way of meeting the demand for RCM predictions. It has configured the third-generation Hadley Centre RCM so that it is easy to set up and can be run over any area of the globe on a relatively inexpensive fast PC. This, along with software currently being developed to allow display and processing of the data produced by the RCM, will form PRECIS.

The intention is to make PRECIS freely available for use by developing-country scientists involved in vulnerability and adaptation studies conducted by their governments, such as those to be reported in National Communications to the UNFCCC. It is assumed that scientists in a group of neighbouring countries can work together so that they can configure the model over their own region and run their own regional climate-change predictions; the advantages of this are discussed in the box below. The PRECIS RCM needs to be driven at its boundaries by data from a GCM and these will also be supplied, corresponding to a range of emissions scenarios. National climate-change scenarios can then be created locally for use in impact and vulnerability studies using local knowledge and expertise. Some training courses would be run, and user-friendly supporting software and online help will be provided to allow local groups of countries to use PRECIS largely independently.

This project will lead to much more effective dissemination of scientific expertise and awareness of climate-change impacts than could be achieved by simply handing out results generated from models run in developed countries. Later in this report, we show some case studies of PRECIS used over China and over southern Africa. We also show an example of how data from the PRECIS RCM have been used to look at the impact of climate change on water resources over southern Africa. Sample displays of PRECIS configured for a southern Asian region and China are provided on the next page.

Using PRECIS for groups of countries

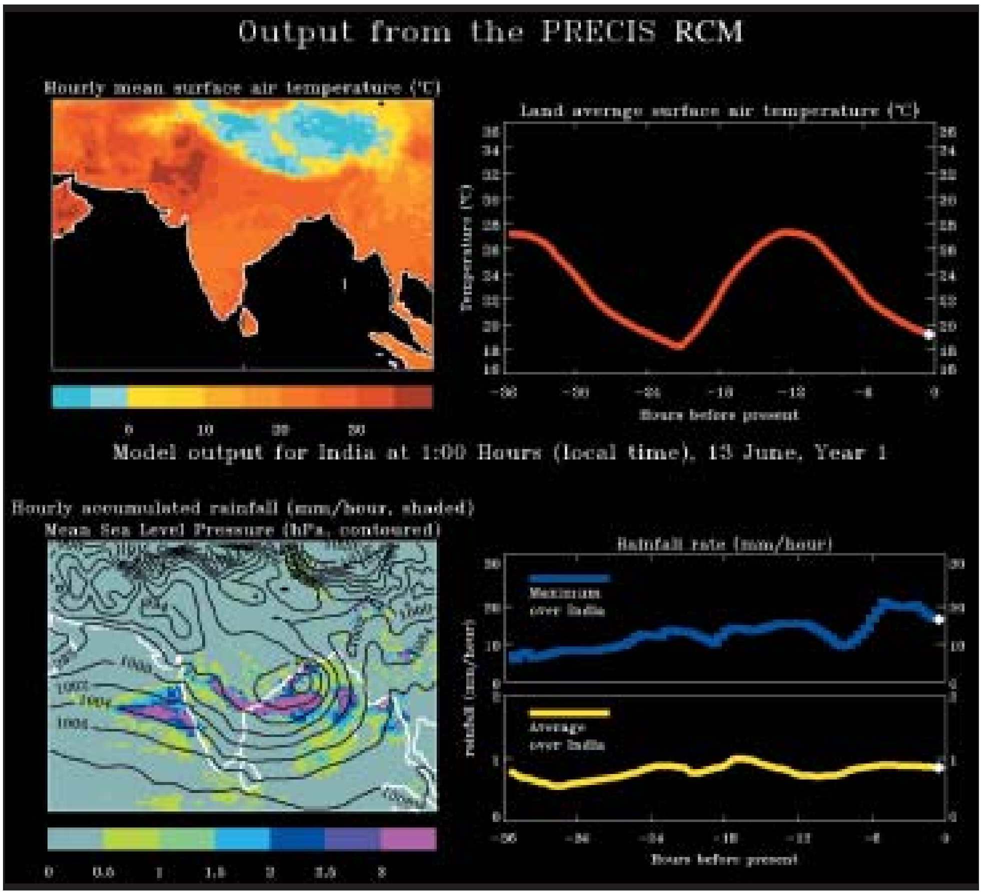
PRECIS will usually cover regions encompassing several countries that may find it useful to work together. Because an RCM is driven by a GCM field at its boundary, there is a strip about 400 km wide where adjustment between the two models is taking place, and where RCM data are not useable. Hence the minimum working area is 5,000 km by 5,000 km for it to be efficient, which will generally be big enough to cover a number of countries (for example, the southern African domain used in the case studies).

There are distinct advantages to countries working together in order to explore the range of uncertainty in climate predictions. Uncertainty in predictions arises from three distinct causes: uncertainty in future emissions, uncertainty in how the climate will respond to emissions, and natural variability (see box on page 12, *Uncertainties in climate-change predictions*). To quantify the range of uncertainty in predictions it is desirable that many RCM experiments should be run, covering:

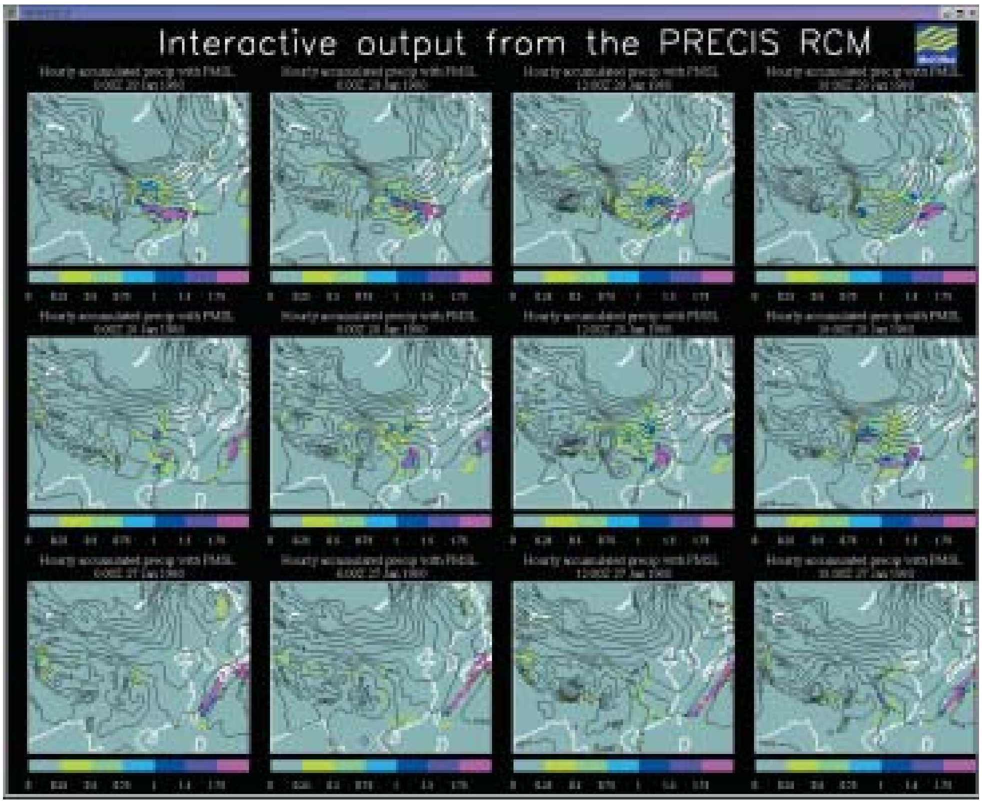
- a range of SRES emissions scenarios (e.g. B1, B2, A2, A1FI), to cover the uncertainty in future emissions;
- a range of climate models from the main modelling centres, to cover the uncertainty in climate response;
- different initial conditions, to quantify the uncertainty due to natural variability;
- different time periods (e.g. 2041–70, 2071–2100) but, if this is not possible, then the later period (2071–2100) should be modelled, and patterns of change for earlier periods can be interpolated from this.

While these could all be done by one country, it is obviously much more efficient and quicker for the work to be shared and the results exchanged.

Training on the use of PRECIS would be more efficient in groups of people from several countries rather than being done individually. This would also promote collaboration between countries in a region. Lastly, many impacts models will extend over a large area, and the impacts can be calculated just as easily for a whole region as for a single country. The new GEF-funded programme, AIACC (Assessments of Impacts of and Adaptation to Climate Change in Multiple Regions and Sectors, www.start.org/Projects/AIACC/aiacc.html), is based on groups of countries, as in many cases they have similar vulnerabilities and face similar impacts from climate change.



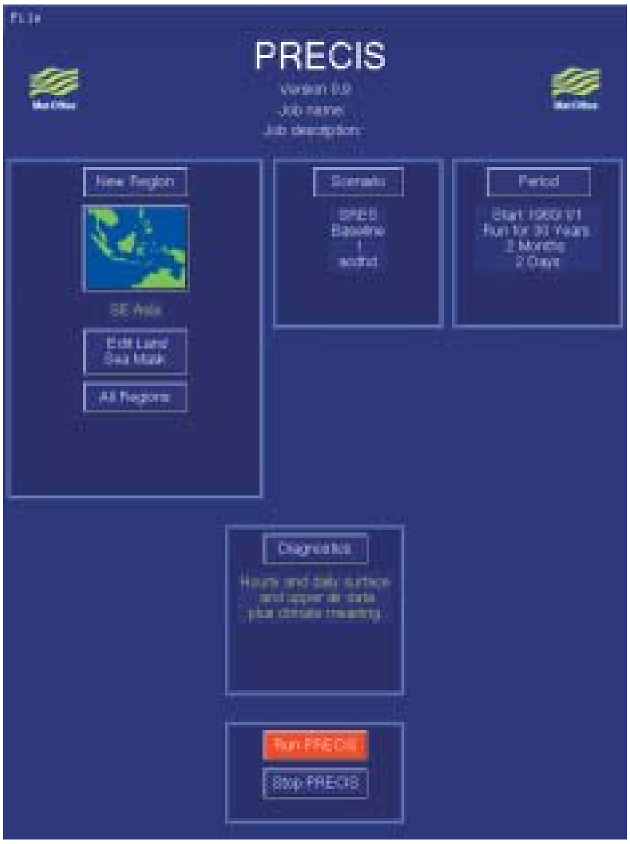
Example output monitoring the PRECIS RCM running over a southern Asian region showing (from top left, clockwise): surface temperature over the region's land areas averaged for the model time displayed; a time-series of average temperature over India for the model's previous 36 hours (the diurnal cycle can be clearly seen); maximum and area average rainfall over India for the same 36-hour period; and a map of rainfall and surface-pressure isobars for the model time displayed.



Alternative output monitoring of the PRECIS RCM, this time running over China and showing six-hourly maps of rainfall and surface pressure isobars for the three days of model time displayed.

6 How do we use PRECIS?

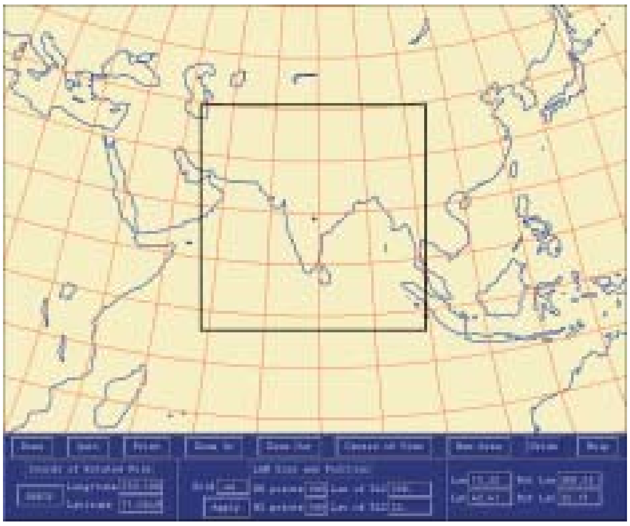
Once PRECIS is installed on a PC and started, the user is presented with a graphical menu (shown below, left) which allows the domain (area) of the model to be specified by choosing an appropriate central point and drawing a rectangular box around it (below right). It also asks the user to specify the length of simulation (10, 20 or 30 years) and the particular driving fields to be used. The current options are quasi-observed data, GCM simulations of current climate and predictions of future climate under SRES emissions scenarios. The user will also have to decide what quantities from the model output should be saved, and how often. In principle, all the model quantities, at every grid point from the surface to 30 km in the atmosphere, could be saved at every time-step. However, this would produce an enormous amount of data that would be almost impossible to store on a PC.



The interface to the PRECIS RCM. The first row of buttons start graphical interfaces (the first is shown on the right) to set up the model for the chosen region. The button on the second row starts a graphical interface to define the data the model will display when running and will archive. The bottom buttons start (or restart, if necessary) and stop the RCM simulation.

The model prediction can then be started, and the model will step forward every five minutes of model time (about four seconds of real time), calculating the new state of the climate system at each step. During the prediction run the output can be monitored in a number of ways, for example, displaying a map showing rainfall or temperature patterns every model hour, or plotting a graph of temperature over a single grid square covering an area of interest (see page 9). Some technical parameters can also be displayed so that any problems can be quickly identified. If the prediction run is stopped part-way through (either deliberately or because of a power failure, for example) then it can be easily restarted without loss of data.

In addition to making data from the RCM predictions available for impacts assessments, it can be valuable in its own right to publish this information (with some simple analyses) in the form of maps and diagrams. For example, maps of changes in quantities (such as maximum and minimum temperature, rainfall, soil moisture) for each of the four seasons and as an annual average, for the period 2071–2100, can be easily generated by the RCM user (see case studies for examples). Further analysis can generate quantities such as change in number of days with heavy rainfall, with temperatures greater or less than a given threshold, or changes in the number of droughts. A booklet, combining model predictions with data on observed climate, can not only be a useful source of information, but also can have the effect of making the issues of climate change more visible to governments and stakeholders. Such a booklet has been produced in the UK (see www.ukcip.org.uk/scenarios/index.html).



Setting up the domain for PRECIS.

PRECIS: some technical details

PRECIS will be supplied on two DVD-ROMs. It should be installed on a PC having the recommended minimum specification of a 2 GHz processor, 512 MB of memory, 60 GB of disk space and a tape drive to allow off-line storage of input and output data. The PC is required to be running the easily installed GNU/Linux operating system. A PC having 2 GHz Pentium 4 or equivalent Athlon processor takes approximately five to six weeks to run a validation simulation of 10 years using quasi-observed boundary conditions, and five to six months to carry out a 30-year simulation of current or future climate. (The latter is computationally more expensive, as it includes a representation of the sulphur cycle and the impact of sulphate aerosols on climate.) One 30-year experiment would produce 150 GB of data, giving a comprehensive description of the simulated climate. These integration times seem long, but they are comparable to the time taken for climate predictions made on supercomputers at large climate-modelling centres.

Hadley Centre GCM fields of global quantities, which are required as initial and boundary conditions to drive the PRECIS RCM, will be supplied on DVD-ROM and tape.

Online support will consist of a web site and mailing list, both maintained by staff at the Hadley Centre. These will provide users with details of the current status of the project, provide hints and answer queries, enable users to exchange data and methods, and supply updates and modifications to the model.

Included on the standard-release DVD-ROMs will be:

- executables and source of the PRECIS RCM and control code;
- one year of data for RCM boundary conditions;
- software to set up, control and monitor the PRECIS RCM;
- software to automatically archive data produced by PRECIS;
- software to process the generated data, e.g. to form multi-annual means, distributions or time-series from the archived data;
- software to display the processed data; and
- software to extract data in a form that can be used by impact models.

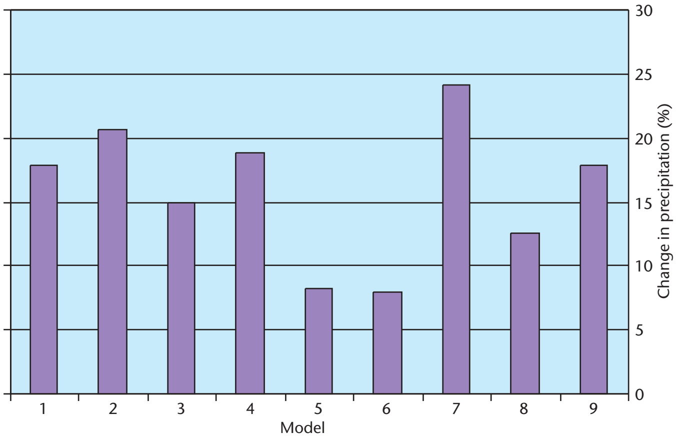
7 Limitations of RCMs for climate-change scenarios

In common with other techniques, RCMs do not yet provide all the solutions for generating climate-change scenarios. There will be errors in their representation of the climate system and their resolution will not be sufficient for some applications. In addition, there are two main limitations to their use in conjunction with GCMs.

Predictions from an RCM are dependent on the realism of the global model driving it; any errors in the GCM predictions will be carried through to the RCM predictions. This limitation is shared by all techniques for generating realistic climate scenarios.

Because different GCMs represent the climate system in different ways, predictions that they make at a regional scale can be very different (see right). As there is currently no assessment available of the quality of the GCM predictions, ideally an RCM should be driven by predictions from a range of GCMs to explore uncertainty. However, there are many practical problems yet to be solved before it is easy to do this. Firstly, interfacing RCMs with a range of GCMs is a complex technical issue which is only now beginning to be addressed. Secondly, the data requirements of RCMs are very substantial and these have to be planned for before running a GCM experiment. Thirdly, the data volumes are currently expensive to archive and time-consuming to transfer. Fourthly, the computing resources needed to run an RCM driven by a large number of GCMs are substantial.

Ways in which these limitations are being addressed are discussed later.



Area-averaged changes in summer rainfall for the period 2071–2100 over southern Asia as predicted by nine coupled models forced by the A2 emissions scenario (taken from Chapter 10 of the Scientific Basis of the IPCC Third Assessment Report). In other areas predictions can show much greater differences in magnitude and even sign.

Uncertainties in climate-change predictions

When assessing the impacts of climate change and the vulnerability of a country, it is important to use not just one climate scenario, but a number that attempts to cover the range of uncertainty. Uncertainty arises from three main causes: the magnitude of future emissions, the response of climate to these emissions, and natural variability.

A. Future emissions

As we do not know how emissions of greenhouse gases will increase in the future, we have driven the Hadley Centre GCM with emissions which would result from four storylines, developed in the IPCC Special Report on Emissions Scenarios (SRES), which essentially cover the range of uncertainty. These are labelled A1FI, A2, B2 and B1 in order of decreasing emissions. The resulting global temperature changes range from about 2 °C to 5 °C, representing the uncertainty due to future emissions.

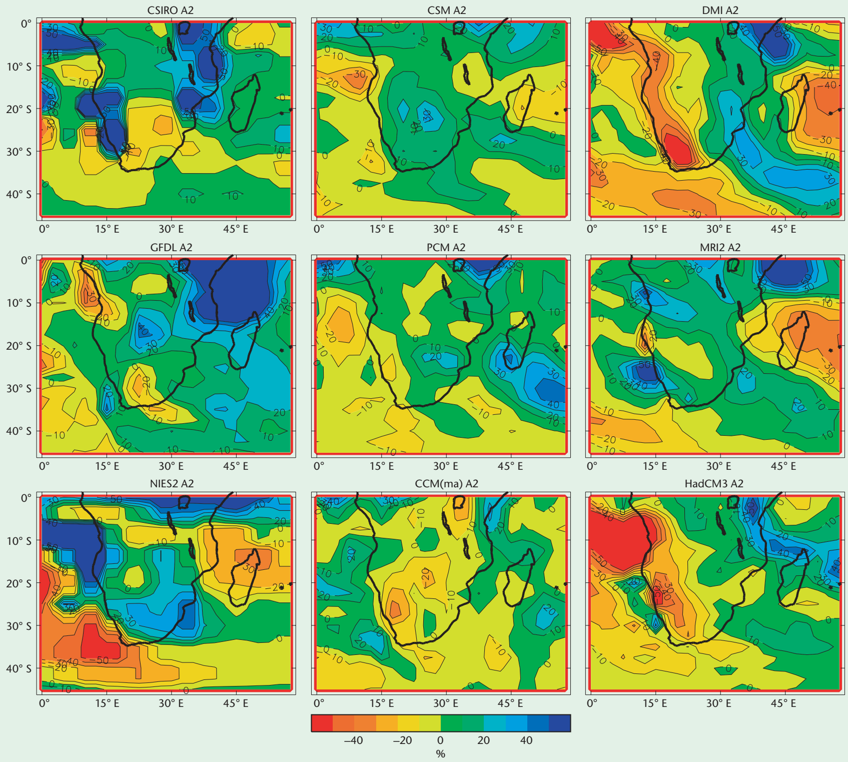
B. The response of the climate system

Because we have an imperfect understanding of the way the Earth's climate system works, no climate model can give an accurate prediction of climate change. We do not know what the true uncertainty in predictions is, but we can make an estimate of this by taking predictions from a range of climate models. For example, the global mean temperature resulting from A2 emissions ranges from 4.7 °C in the most sensitive model reported in the IPCC Third Assessment Report Technical Summary, to 2.7 °C in the least sensitive.

At a regional level, the spread in predictions from GCMs can be even larger. For example, the figure below shows the range of predicted rainfall changes over southern Africa from nine GCMs. However, the 2001 IPCC Scientific Assessment has shown that agreement between these GCMs on regional-scale seasonal-mean changes has improved. For example, models show consistency in relative warming in three-quarters of world land regions and in the sign of precipitation change in two-thirds of regions. Consistency is better at mid and high latitudes.

C. Natural variability

A further type of uncertainty, very different from those above, comes from the natural variability of climates. For a given period in the future, natural variability could conspire to either add to the underlying man-made change, and thereby make conditions even more pronounced, or could subtract from it, to make it less pronounced. Because we cannot predict natural variability, and are unlikely to be able to do so for some time, we have to live with this uncertainty by quantifying it. This is done by running the climate model with different initial conditions. Results over the eastern part of England, using this technique, show that a predicted decrease in summer rainfall by the middle of the century of 16% (averaged over four model runs) could be as much as 27% or as little as 2% depending on whether natural variability tended to give drier or wetter conditions.



Thirty-year mean change in summer (DJF) precipitation (%) for the 2080s relative to the present day under the A2 emissions scenario for nine different fully coupled ocean–atmosphere GCMs. [CSIRO: Commonwealth Scientific and Industrial Research Organisation's Mk.2 model (Australia); CSM: Climate System Model, National Center for Atmospheric Research (USA); DMI: Max-Planck Institute for Meteorology (Germany) and Danish Meteorological Institute's ECHAM4-OPYC model; GFDL: Geophysical Fluid Dynamical Laboratory's R30-C model; PCM: Department of Energy (USA) and the National Center for Atmospheric Research's Parallel Climate Model; MRI2: Meteorological Research Institute's (Japan) GCM (V2); NIES2: Centre for Climate Study Research (Japan) and National Institute for Environmental Studies' (Japan) GCM (V2); CCC(ma): Canadian Center for Climate (Modelling and Analysis) CGCM2 model; HadCM3: Hadley Centre GCM]

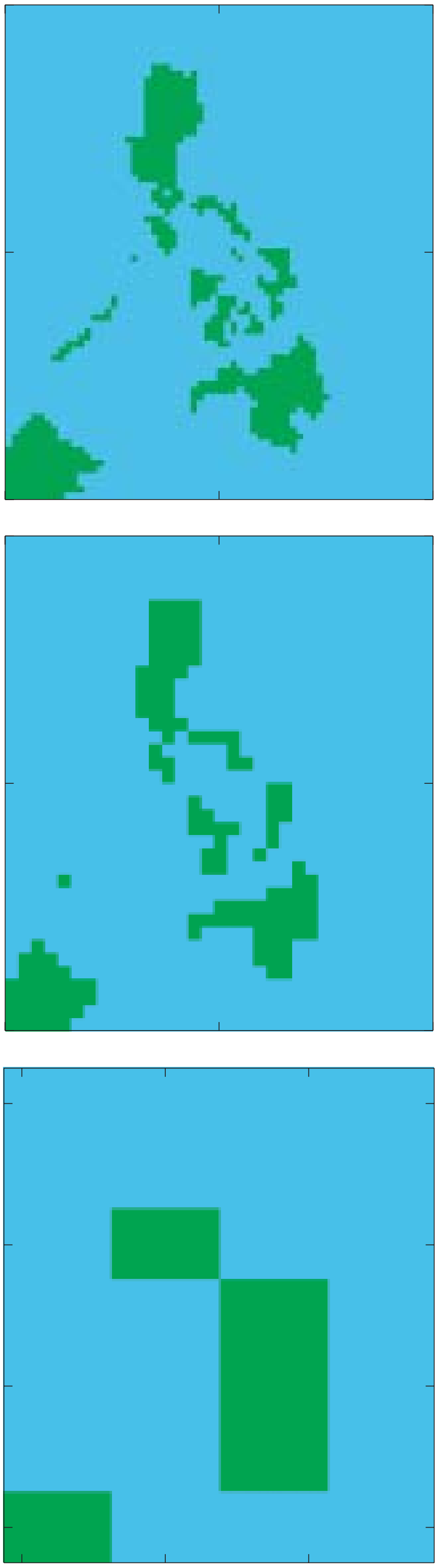
8 Further developments

Although PRECIS is a major step forward in making climate modelling more readily accessible, developments over the next few years are expected to improve it further. Some of these anticipated developments are as follows.

1. The global models used to drive the RCM and the RCM itself will continue to be improved. Three main areas will be addressed:

- increasing resolution in both the atmosphere and ocean;
- improving the representation of processes in the atmosphere (e.g. clouds) and ocean (e.g. eddies); and
- including new processes that provide feedbacks onto climate (e.g. the carbon cycle, atmospheric chemistry).

2. The current resolution of the RCM is 50 km. A 25 km resolution version of this has already been developed and is currently being evaluated. In the next three years, a 10 km RCM is planned for application to smaller domains. This will improve the realism of the models, further allowing more geographic detail to be resolved and better simulation of extremes. The extra detail is demonstrated clearly when resolving the islands of the Philippines at 50 km and 25 km (see right). Unfortunately, an RCM with twice the resolution will be four to eight times slower, so the practical application of higher-resolution models for other than very small regions awaits faster PCs or the use of PC clusters (networked PCs providing a parallel-processing facility).
3. A regional ocean model developed for shelf seas forecasting will be coupled to the atmospheric RCM to provide a coupled regional modelling system. Taken with improvements in GCMs, this will allow direct predictions of regional sea-level rise and storm surges as well as providing high-resolution regional ocean climate scenarios consistent with those from the atmospheric RCM.
4. Software will be provided to allow PRECIS to use data from other centres' GCMs. It is important that the uncertainty from the different regional responses in different GCMs is explored, which could be done by using them to drive the PRECIS RCM. This is currently not possible as software to reformat the data from these GCMs is not available and, in many cases, the data themselves are not available. The uncertainty in the coarse-resolution GCM predictions over any region can currently be explored by obtaining data from the IPCC DDC or using, for example, the SCENGEN generator.
5. Just as climate modelling centres develop independent GCMs, many of them also develop RCMs, and these can give a spread of predictions. It is hoped that some of these can be compared over the next two to three years and the results gained will lead to a first estimate of the uncertainty in predictions of detailed climate changes. This is currently being started in Europe under a European Commission-funded project, PRUDENCE.



The representation of the Philippines in RCMs with resolutions of 25 km and 50 km, and in the GCM (400 km resolution).

Case study: Assessing PRECIS RCM simulations of climate over China

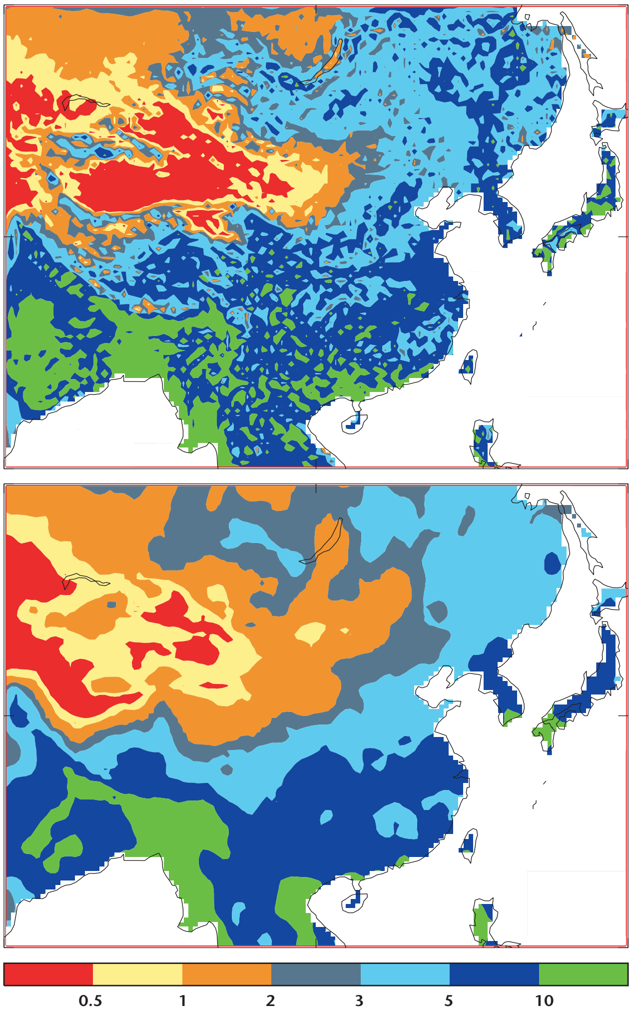
There are two main approaches to using predictions of climate change in impacts assessments, which can be characterised as direct and indirect. Using the direct approach, predictions from the regional climate model are input directly into the impacts model. This approach is straightforward to implement and means that the impacts model can better exploit the fine temporal resolution (for example, daily) of the RCM. However, if the regional model does not simulate the current climate well, then the prediction of future climate will not be reliable, and hence neither will its impacts. This direct approach is generally not appropriate for GCM predictions, because of their coarse resolution.

The alternative, indirect, approach uses predictions from the RCM 'future climate' (for example, 2071–2100) and 'recent climate' (for example, 1961–90) to construct scenarios of climate change — that is, the difference between the prediction and the simulation. In the simplest method, this change in climate is then added to observed climate, to form a scenario of future climate. However, in many cases, the impacts of climate change are likely to be felt through changes in climate variability and extremes, as well as in mean climate. To allow for this, changes in the distributions of quantities (such as temperature and rainfall) need to be combined with observed climate data. There is no unique way of doing this; the most appropriate method can depend upon the quality of model simulations and the particular impact being studied, (e.g. water resources, agriculture).

For both the direct and indirect approaches, an assessment of the quality of the model simulations is essential. An important starting point in this process is to compare the RCM simulation of current, or recent, climate with observations. This simulation can be generated by using GCM simulations of current climate to 'drive' the RCM; this is required in any case, as it is the baseline climate from which the climate-change scenario is derived. Such a comparison, for the case of rainfall over Britain, is shown on page 4.

The second way of assessing the quality of model simulations is to drive the RCM with 're-analyses' of observations; these can be regarded as the best available data of real day-to-day changes to the state of the atmosphere over a period of decades. They are available from the National Center for Environmental Predictions (NCEP) in the US or the European Centre for Medium-range Weather Forecasts (ECMWF) in the UK. The RCM simulation when driven by re-analyses will not play a direct role in the creation of the climate-change scenarios, but it has considerable value in allowing an assessment of errors in the RCM simulations and the reasons for these. This is because RCM simulations driven by GCM will inherit errors from the GCM, so it is not easy to explain their source. On the other hand, RCM simulations driven by re-analyses of observations can be used to pinpoint the reasons for the errors; this provides guidance on which physical processes are being well represented in the model and hence on which aspects of the model predictions of climate change can be used with confidence. It also helps us to target future development of the model.

PRECIS is being used in a project, joint with the Chinese Academy of Agricultural Sciences, to generate climate-change scenarios for China. An initial experiment has been performed with the PRECIS model, using boundary conditions from a re-analysis of three years of observations. As shown below, the main patterns of summer rainfall simulated over the period match well with the observations, although there are some local differences. During this period, there is a tendency for the model to simulate too much rainfall in southern and north-eastern regions. This would imply that an assessment of current water availability based on the model would be too high. Then, if the model predicted drier summers in the future, the model rainfall error could imply predictions of increased drought which may be exaggerated, or the risk of flooding underestimated.

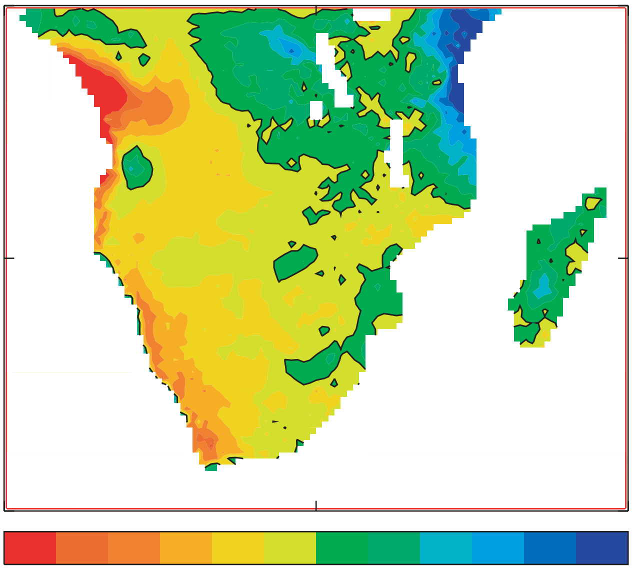


Summer precipitation for the years 1979–81 as simulated by PRECIS, using boundary conditions from a re-analysis of observations for that period (top) and as observed in a global land climatology (bottom). Units are mm/day.

Case study: Application of the PRECIS RCM to southern Africa

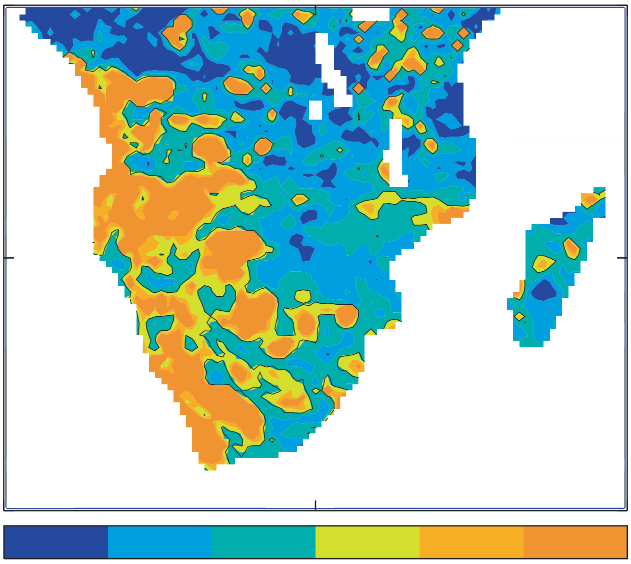
Because water is a limited resource in many sub-Saharan African countries, this region may be very vulnerable to human-induced climate change. Hence, the PRECIS model has been applied to this region in order to derive high-resolution climate-change predictions.

Under the SRES A2 emissions scenario, the RCM predicts an average surface warming over the subcontinent of 3.8 °C in summer and 4.1 °C in winter by the 2080s. It also predicts a reduction in rainfall over much of the western and subtropical subcontinent, and wetter conditions over eastern equatorial and tropical southern Africa during summer, when most rain falls (see below).



Change in mean summer (DJF) precipitation over southern Africa for the 2080s relative to the present day for the A2 emission scenario.

Much of southern Africa experiences a high degree of intra- and interannual rainfall variability, and the region is particularly susceptible to floods and drought. The predicted decrease in summer rainfall over the western half of the subcontinent, specifically Angola, Namibia and South Africa, is associated with a decrease in the number of rain days, as well as a small reduction in the intensity of rainfall falling on any given rain day. In contrast, the increase in rainfall over Tanzania and the Democratic Republic of Congo is related to an increase in the intensity of rainfall rather than a change in the number of rain days. In the fields of hydrology and civil engineering, a common means of examining extreme rainfall is in terms of return periods. For example, structures such as bridges and dams are designed to withstand the largest precipitation event anticipated within a particular period (e.g. the one-in-20-year flood event). An analysis of the amount of rainfall associated with the one-in-20-year flood event, shown here, indicates that rainfall may become more extreme over large areas of Mozambique, Zimbabwe, Zambia, Tanzania and the Democratic Republic of Congo, whereas less extreme rainfall is predicted over western regions.



Summer rainfall return periods for the 2080s, under the A2 emissions scenario, with respect to the present-day 20-year rainfall return values. Values under 20 imply the present-day extreme precipitation event is more likely in the future scenario, and vice versa.

Drought is probably the most significant climatic extreme impacting southern African agriculture, water resources and natural ecosystems. In addition, the combination of dry-land farming (i.e. reliance on rain, with little or no supplemental irrigation), which is still widely practised in southern Africa, and the dependence on water-demanding maize, means that food production is very vulnerable to the vagaries of rainfall within the growing period. The RCM predicts that summer drought will be more likely in the future over much of southern Africa, including some areas where mean rainfall increases. There is an increase in the length of dry periods in summer over most of the region, with statistically significant changes over Mozambique, eastern Zimbabwe, northern Angola, western regions of the Democratic Republic of Congo and along portions of the west coast of southern Africa. Area-averaged increases in maximum dry-spell length are largest in the western equatorial (59%), western tropical (32%) and eastern tropical (44%) regions. There is also a significant increase in the frequency of prolonged summer dry spells (five or more consecutive dry days) over small portions of Angola, Namibia, Botswana, Zimbabwe and Mozambique.

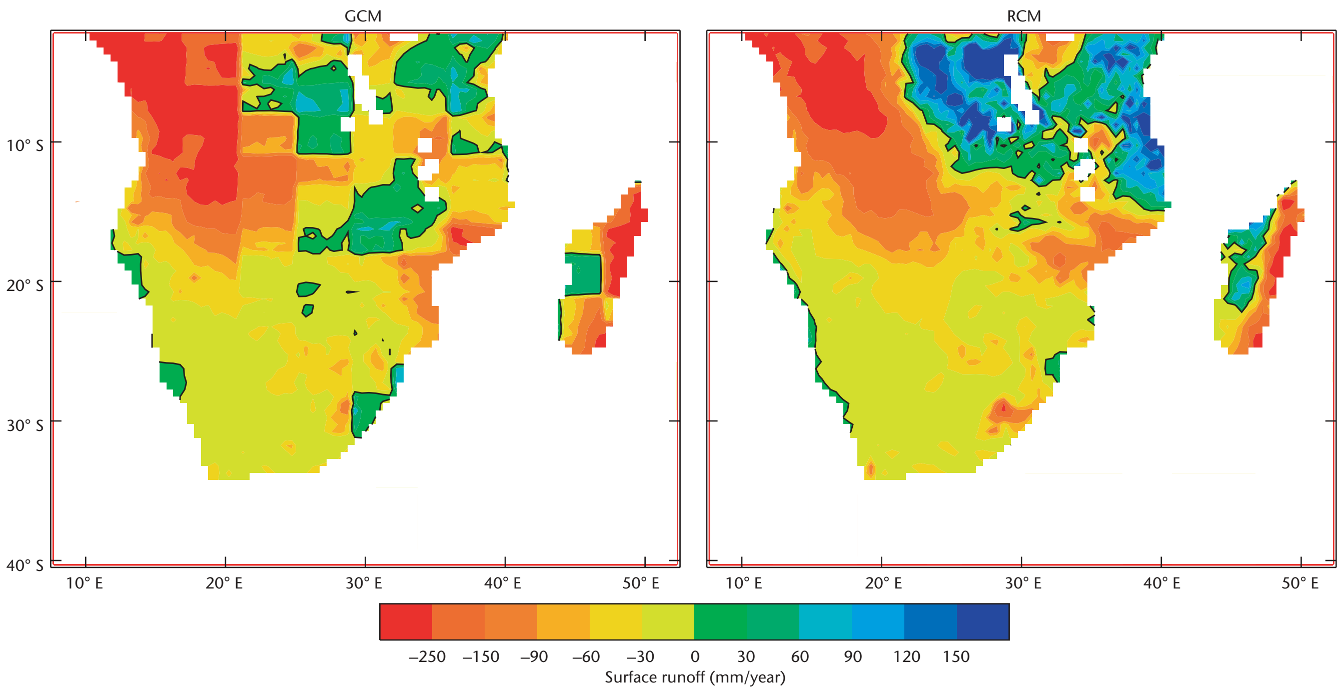
Drought is not determined by precipitation alone. Other important physical factors include air temperature, soil-moisture availability, river flow and dam levels. The combination of reduced rainfall and increased temperatures, which coincide spatially over much of southern Africa in the future scenario examined here, means that increased evaporation could further exacerbate the drought potential.

Case study: Impacts of climate change on hydrology and water resources in southern Africa

Predictions of changes in climate resulting from the A2 emissions scenario, taken from both the Hadley Centre global model and the PRECIS RCM, have been applied by the University of Southampton to a hydrological model of southern Africa. This operates on a spatial resolution of half a degree, containing about 100 river catchments over the area shown, and uses data on precipitation, temperature, wind speed, humidity and net radiation from the climate models. The changes in mean monthly climate between the modelled recent climate (1961–90) and the end of the century (2071–2100) were applied to an observed monthly climatology for 1961–90 as input to the hydrological model. The model simulates a 30-year time-series of daily surface runoff, which is summed over the whole catchment to calculate river flow, although data are only output for each month.

The diagram below shows the change in annual average surface runoff across southern Africa between the recent climate and that of the 2080s, using input climate data from the GCM and from the PRECIS RCM. The pattern of change broadly follows that in rainfall, but with larger areas showing a reduction in river flows than in rainfall because of the increased evaporation in the warmer future climate. On a broad scale, as expected, the results using the GCM and RCM agree. River flows generally decrease south of 20° S by 30% or more (although, of course, absolute amounts are small in these arid regions), and in the west, between 20° S and the equator, large decreases in river flows are evident. In other parts of the region modelled, for example Tanzania and the Democratic Republic of the Congo, the spatial pattern and magnitude of change predicted by the RCM is very different from that in the GCM. Some areas, which show little or no increase in river flows using GCM predictions, show substantial increases in river flows under RCM predictions. Hence the impact assessment and adaptation policy based on GCM predictions could be in error.

The University of Southampton model also uses projections of population, etc. to calculate each country's water stress (availability of water per capita). They find that, in all the countries which will be stressed by the end of the century (for example, South Africa, Zimbabwe and Swaziland), climate change adds substantially to this stress.



The change in annual average surface runoff between the recent climate and that predicted for the 2080s as calculated from GCM predictions (left) and from RCM predictions (right). (Nigel Arnell, University of Southampton)

Summary of PRECIS components

- User-interface to set up RCM experiments
- The latest Hadley Centre RCM
- Data-processing and graphics software
- Boundary conditions from the latest Hadley Centre GCM
- Training course and materials

The Regional Modelling Group at the Met Office's Hadley Centre

The model development work was carried out by a number of scientists, past and present, at the Hadley Centre: James Murphy, Maria Noguer, David Hassell, Debra Hudson (current visiting scientist from the University of Cape Town), Simon Wilson (PRECIS systems manager), Erasmo Buonomo, Maria Russo, Dave Hein, Ruth Taylor and Balakrishnan Bhaskaran (past visiting scientist from the Indian Institute of Technology, Delhi), and Xu Yinlong (visiting scientist from the Chinese Academy of Agricultural Sciences, Beijing). Storm surge modelling is carried out by Jason Lowe. The head of the Regional Modelling group is Richard Jones; John Mitchell heads the Climate Prediction Group and the Climate Prediction Programme is managed by Geoff Jenkins.

This report is also available at:

www.metoffice.com/research/hadleycentre/pubs/brochures/B2002/precis.pdf

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