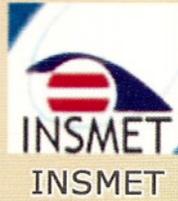


Glimpses of the Future

A BRIEFING FROM THE PRECIS CARIBBEAN CLIMATE CHANGE PROJECT



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A Briefing from the PRECIS Caribbean Climate Change Project
February 2007



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Foreword

CARICOM States, along with other Small Island Developing States (SIDS) and Low Lying Coastal States around the globe, are facing a major challenge to their aspirations for development from the anticipated impacts of global climate change. Indeed, the Barbados Programme Of Action (BPOA), articulated at the SIDS meeting in Barbados in 1994, accorded climate change the highest priority, as an issue which needed the urgent attention of countries. This urgency, was further underlined at the SIDS follow up meeting in Mauritius in January, 2006. It identified global climate change as one of the most serious global environmental problem threatening the very viability of several SIDS.

Since the Barbados meeting, Caribbean Governments have vigorously pursued the goal of building regional capacity to mitigate the projected impacts of climate change and also to decrease our present day vulnerability to weather related disasters, originating from climate variability. Emphasis has been to aim at better defining, for policy-makers in the region, the nature and extent of the risks we will face, as a result of future climate change. Armed with this information, our policy-makers would better be able to design measures which should be put in place to increase the resilience of our human, natural, social, and economic systems, to the expected deleterious impacts of climate change.

This publication represents a joint effort in the region to provide the policy makers, with vital information. For this we would like to express our sincere appreciation for the support received from the World Bank and the Global Environmental Facility, through the Mainstreaming of Adaptation to Climate Change Project and the Japanese Trust Fund, to the Caribbean Community Climate Change Centre (CCCCC) to facilitate the implementation of this work. I am encouraged by the collaborative effort between the Institute of Meteorology in Cuba and the Mona and Cave Hill Campuses of the University of the West Indies for producing this publication. It is a fine example of the effectiveness of regional collaboration in helping us to meet global challenges such as those we may face with climate change. We, in the region, look forward to the further outputs from this commendable initiative and urge that no effort be spared, in ensuring the information is disseminated at all levels of the policy and decision-making in the Caribbean.



Said Musa

The Hon. Said Musa
Prime Minister of Belize, with
Responsibility for
Sustainable Development
(including Environment and
Disaster Management and Water)
for CARICOM

Summary

- Global average temperatures have risen by about 0.6°C since the 19th century. It is likely that the rise over the past 50 years is mainly caused by fossil fuel burning and other human activities.
- The annual mean temperatures over most of the Caribbean region have shown an increasing trend during the past few decades.
- Global climate models predict a rise in global annual average temperatures, between 1990 and 2100, of 1.5°C to 5.8°C, taking into account both the range of future emissions, projections developed by IPCC and a range of different climate models.
- The PRECIS Caribbean Project focuses on how climate change could affect the countries within the Caribbean region. Noting that global climate models (GCM) do not have sufficient resolution to show most of the Caribbean islands, a version of the Hadley Centre regional climate model (PRECIS) has been deployed within the Caribbean Climate Change Modelling Centres at resolutions of 25 km and 50 km respectively. This can resolve the climate processes in most of the islands.
- Although a wide range of results from regional climate models are not yet available, the best possible estimate of the range of model uncertainty is made by using results from global models. Changes under other future emissions scenarios are estimated by scaling the Medium–High climate model predictions of the Hadley Centre global climate models.
- Emissions uncertainty has been partially addressed by generating multiple scenarios appropriate to the IPCC definitions of A2 and B2 future emissions scenarios.
- The Caribbean is expected to warm by 1°C to 5°C by the 2080s under Medium–High Emissions scenario. The greatest change is expected in the summer.
- The Caribbean is expected to be up to 25% drier by the 2080s under Medium–High Emissions scenario. The southern Caribbean will be drier than the north.
- Although these scenarios are a clear step forward, many uncertainties are attached to them. For decisions involving large investment, it is recommended that these uncertainties should be explored in more detail.

1. Introduction

The Earth's climate is changing! Human influence is changing the composition of the atmosphere and in turn altering the earth's average temperature and its sea levels. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC TAR) concludes that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities mainly brought about through changes in the atmospheric composition due to increases in emissions of greenhouse gases and aerosols."

An overriding concern is: "How well will we cope in a future world which exhibits a changed climate?" This concern is reflected in the UN Framework Convention on Climate Change, and is driving the move towards the Kyoto Protocol. To answer the question, we need to assess the potential impacts the changing climate is currently having or will likely have on the world as we know it today. This will, in turn, facilitate the identification of reasonable coping strategies or adaptation options which can be implemented in our respective communities at various levels.

But, to assess the impacts of climate change means we must at least have a 'best guess' of what future climates will be like. Such guesses (or 'climate scenarios') currently exist on the global scale and provide useful 'initial' information for scientists, researchers and planners who must evaluate climate change impacts in various sectors of our societies and plan appropriate adaptation strategies. However, representing future climates at smaller and more regional scales is a necessity, especially for small island states which are among the most vulnerable to climate change.

In the Caribbean several institutions are working together to produce useful climate information of sufficiently high resolution which will give us an idea of what will happen in our region. This document presents information on this joint initiative and some preliminary results. It is a part of a call to action to begin the process of planning for the future today.

The Earth's climate is changing!

The Kyoto Protocol

The Kyoto Protocol aims at reducing the emissions of carbon dioxide and five other greenhouse gases. It presently covers more than 160 countries globally and over 55% of global greenhouse gas (GHG) emissions.



We need climate information at very high resolutions.

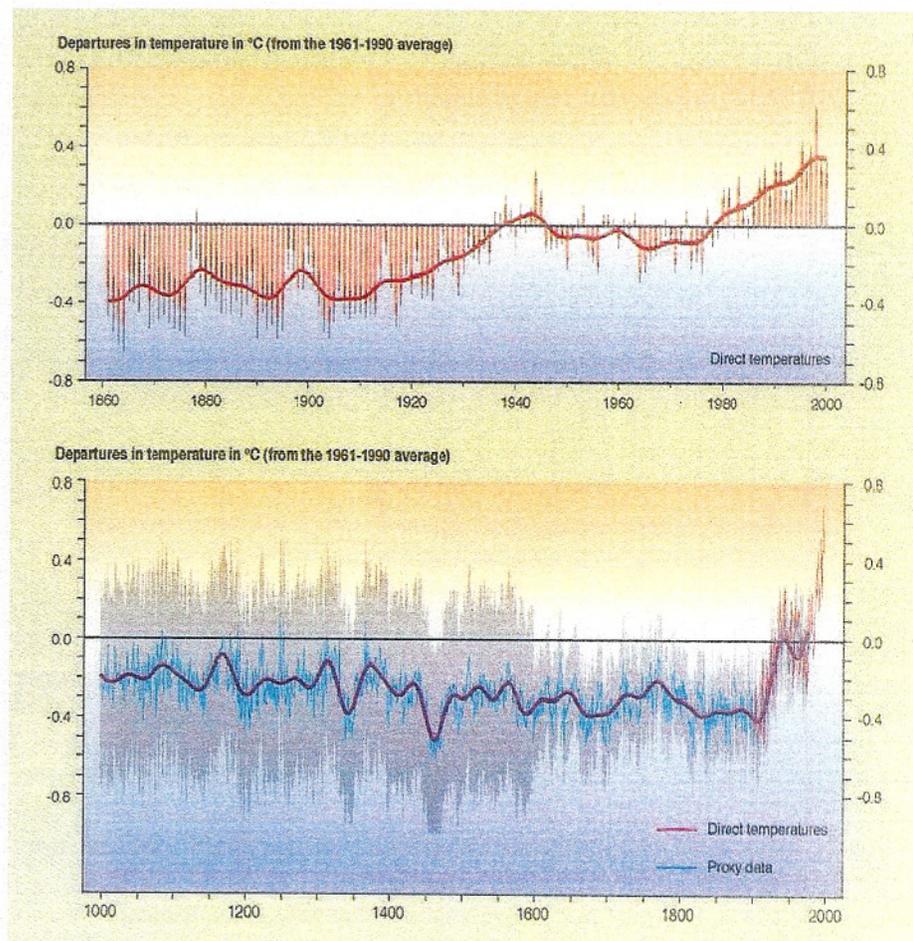
2. How is the Climate Changing?

Global Climate

The state of global climate can be described by the average earth's surface temperature, which is estimated from measurements taken in many places around the world. The records of these global values (Figure 1) indicate that surface air temperature has increased by $0.6^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$ since the 19th century, and this is likely a greater warming than that seen in any other century in the last one thousand years for the Northern Hemisphere. It is also very likely that the 1990s was the warmest decade, and 1998 the warmest year. The evidence above, which comes from Third Assessment Report of the IPCC, is part of the increasing body of observations which gives a collective picture of a warming world and other changes in the climate system.

The earth has warmed by 0.6°C since the 19th century.

Figure 1: Variations of the Earth's temperature for the past 140 years (global) and the past 1000 years (Northern Hemisphere). The figure shows departures from the long term mean. Source: IPCC TAR Synthesis Report.



Other observed changes are related to different weather indicators and include:

- A decrease in diurnal temperature range during the years 1950 to 2000 over land areas.
- Sea ice extension and snow cover decrease.
- Continental precipitation increase over the 20th century in the Northern Hemisphere.
- An increase in heavy precipitation events at mid and high northern latitudes.

Caribbean Climate

The climate in the Caribbean region has also changed in a manner very consistent with the observed variations at global and northern hemisphere levels. Temperature records have shown an increase in the last century, with the 1990s being the warmest decade since the beginning of the 20th century. In the region, 1998 also appears as the warmest year on record (Figure 2).

The observed regional temperature increase is confirmed by other studies done by national institutions within the region. These studies also provide insight into other ways in which our regional climate might be changing. For example, results from studies done by the Institute of Meteorology (INSMET) in Cuba and the University of the West Indies (UWI) indicate that:

- The mean temperatures of individual Caribbean territories similarly trend upward for periods of three decades or more to the present. Figure 3 shows the trends for the Eastern Caribbean.
- At the end of the 1970s a significant warming in the lower part of the atmosphere was detected in the region. The warming is evident in Figure 2 and in some of the diagrams of Figure 3 and supports the idea that changes are occurring in background climate conditions. It is also consistent with significant variations in circulation patterns that have been detected over the North-Pacific sector of North America for the same period.
- The upward trend in the mean temperatures seems to be largely driven by changes in the minimum temperatures. For example, the mean annual temperature in Cuba (1960s to present) has increased by approximately 0.5°C. For the same period, there is a statistically significant increase of 1.4°C in minimum temperatures, but no significant trend in maximum temperatures.
- The diurnal temperature range is decreasing, consistent with global trends. For the region, a two degree change has been detected (1950s to present).
- The number of very warm days in the region is increasing, but, the number of very cold nights is decreasing (1950s to present).
- The frequency of droughts has increased significantly since 1960. In the last few years Cuba has been affected by one of the more intense and longer droughts in the record.
- The frequency of occurrence of other extreme events in the region seems to be changing. Flooding events and hurricane passage through the region have increased since the mid 90s. Tornadoes hail and heavy rains have become more frequent in Cuba since 1977.

It's not only mean temperatures that have changed.

The Caribbean has warmed from the 1950s to present.

Figure 2: Variations of land surface temperature for the Caribbean, estimated from the Climate Research Unit database.

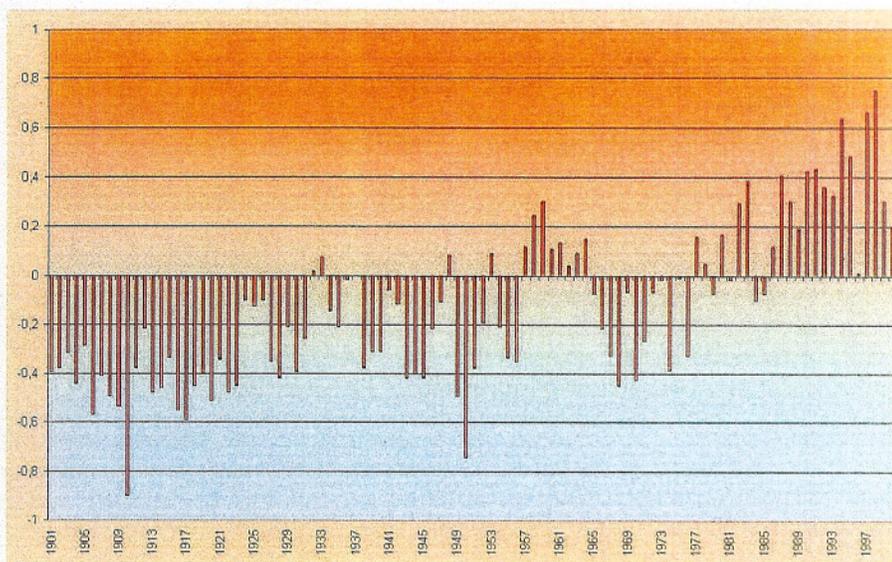
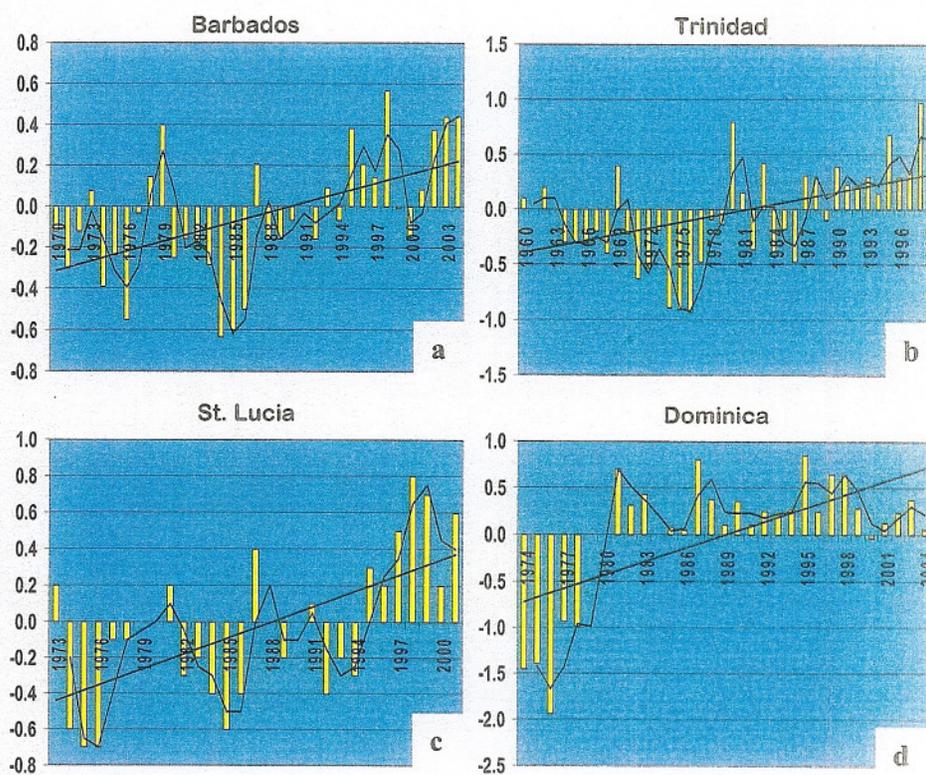


Figure 3: Yearly temperature variation ($^{\circ}\text{C}$) from the mean temperature of the baseline period. (a) Barbados (baseline: 1970-2004) (b) Trinidad (baseline: 1960-1999) (c) St. Lucia (baseline: 1973-2001) (d) Dominica (baseline: 1974-2004). Straight line indicates the trend.



3. What are scenarios and why do we need them?

Scenarios and GCMs

Human activity will continue to affect global climate, even if global emissions of greenhouse gases were to eventually fall below today's levels. This is so because the lifetime of greenhouse gases in the atmosphere is relatively long. So some degree of further climate change is inevitable due to the past and present emissions. How can we estimate what the future climate will look like if greenhouse gases continue to increase?

The climate in fifty to one hundred years from the present, will depend on the rate at which greenhouse gas emissions continue to grow. Because it is impossible to predict this from now, climate scientists, working in conjunction with IPCC, have come up with different "scenarios" of increases in emissions on which to base predictions of future climate. Each scenario is premised on a 'storyline' of how the world might develop i.e. possible changes in population, energy use, economics and technology. The greenhouse gas scenarios currently in use are grouped in families based on the amount of emissions they predict and can be found in detail in the IPCC Special Report on Emission Scenarios (SRES). See also the accompanying box.

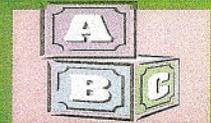
By using the SRES greenhouse gas emission scenarios, it is possible to generate future "climate scenarios". Climate scenarios are simply plausible and physically consistent representations of the future climate based on greenhouse gas emission scenarios. A great variety of methods exists to create climate scenarios. The most common involve using *General Circulation Models* or GCMs to simulate the climate from the present into the future under each SRES scenario. Climate scenarios based on outputs from GCMs are a major source of information for climate scientists today. In fact, GCMs are the best scientific tools currently available to simulate the global climate system response to a change in atmospheric composition.

Selecting which emission scenario to use and the subsequent production of climate scenarios are very important (but often confusing) steps for any vulnerability and assessment study. Some guidance is necessary as the best choice may depend on a number of factors including the geographical region being studied, and the purpose of the vulnerability and adaptation (V&A) study. For example, in a region such as the Caribbean basin, it is very important to produce information at a very high spatial resolution. However, sometimes the spatial resolution is not a relevant aspect, but rather the availability of the different climate variables needed for quantitative impacts studies.

Climate change seems inevitable!

SRES Scenarios

There are four main emission scenarios often seen in the literature. They are labelled B1, B2, A2, and A1F1. They represent respectively: Low Emissions, Medium-Low Emissions, Medium-High Emissions and High Emissions.



A climate scenario is a possible future climate given a set of assumptions.

General Circulation Models (GCMs) provide climate scenario data...

... but GCM data are too coarse in resolution.

Running a Regional Climate Model (RCM) can bridge the resolution problem.

A Problem of Scale

Although the information provided by GCMs has many advantages, it is provided at a resolution of a few hundred kilometers or so. Information on this scale is not very useful for small island territories e.g. much of the Caribbean. In fact, this mismatch of scale between the coarse resolution of the GCMs and the scale needed for regional impacts studies has often been bemoaned by the researchers of the climate change impact community. Indeed, more detailed temporal and spatial information than can be provided directly by a GCM is needed to investigate possible changes in some extreme events e.g. tropical storms and hurricanes.

Fortunately, there are methodologies which can be used to produce high resolution information from the coarser GCM outputs. These are commonly referred to as *regionalization* or *downscaling* techniques and include: 1) regional climate modelling; 2) statistical downscaling; and 3) high resolution and variable resolution time-slice techniques. The latter has rarely been applied to explicit scenario formation for impact studies. The first two procedures utilize the large-scale circulation variables from the GCMs to deduce climate variables on regional scales. An important distinction is that, while the process in regional climate models is dynamic and physically based, statistical downscaling techniques assume a constancy of present day relationships between the large scale GCM variables and the regional climate. This constancy may or may not be true as we go into the future.

There are relative advantages and disadvantages to each technique. Some of the advantages of using a regional climate model (RCM), however, make them an attractive option for regions like the Caribbean. These include the fact that RCMs (i) simulate current climate more realistically especially over regions where the terrain is not flat (ii) predict climate change with more detail (iii) represent smaller islands that are absent in GCMs (iv) are much better at predicting changes in extreme weather (v) can simulate cyclones and hurricanes (vi) can be used to drive other models (vii) produce large amounts of information which can enhance analysis of the future climate. One disadvantage is that, like GCMs, RCMs are computationally demanding, both in terms of running time and demands on storage.

Some More about Regional Climate Models

An RCM is a tool to add small-scale detailed information of future climate change to the large-scale projections of a GCM. RCMs are full climate models and as such are physically based and represent most or all of the processes, interactions and feedbacks between the climate system components that are represented in GCMs. They take coarse resolution information from a GCM and develop temporally and spatially fine-scale information consistent with this, using their higher resolution representation of the climate system. The typical resolution of an RCM is about 50 km in the horizontal. It covers an area (domain) typically 5000 km x 5000 km, located over a particular region of interest.

Source: Jones, RG, Noger, M., Hassell, DC., Hodson, D., Wilson SS., Jenkins, GJ and Mitchell, JFB (2004) Generating high resolution climate change scenarios using PRECIS, Met Office Hadley Centre, Exeter, UK, 40 pp, April 2004.

4. The PRECIS Project

In the last few years, however, RCMs have become less and less the “toys” of large computing centres worldwide. They have become increasingly available to smaller research centres in developing countries (such as those in the Caribbean) which seek to carry out regional experiments to develop context specific climate change scenarios. PRECIS (Providing REgional Climates for Impacts Studies) is one such regional modelling system developed at the Hadley Centre, UK. It is currently being used in the Caribbean to produce future climate scenarios

So what is PRECIS?

PRECIS is a regional modelling system derived from a third-generation Hadley Centre RCM which has been so configured that it can be set up and run over any area of the globe, on relatively inexpensive but fast PCs. PRECIS is freely available for use by developing country scientists involved in vulnerability and adaptation studies conducted by their governments.

The PRECIS RCM is driven at its boundaries by data from the Hadley Centre GCM corresponding to a range of SRES emissions scenarios (see page 5). It produces vast amounts of climate data including standard variables such as temperature and precipitation, for future periods (2070-2100). Because of its high resolution, national climate change scenarios for small countries such as those that make up the Caribbean can, then, be created. Software is also provided for processing, analyzing and displaying the data produced by PRECIS.

PRECIS Fact Box

- Pronounced PRAY-SEE
- Stands for Providing REgional Climates for Impacts Studies
- Is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe.
- Has a horizontal resolution of 0.44° (~50km) or 0.22° (~25km) and 19 levels in the vertical.
- Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all processes formulated in PRECIS.
- PRECIS is forced at its lateral boundaries by the simulations of a high-resolution global model (HadAM3H).
- Currently ensembles of three baseline simulations for the period 1961–1990, three simulations for the A2 future scenario (2071–2100) and one simulation for the B2 future scenario (2071–2100) can be run with PRECIS.

PRECIS is a regional climate modelling system.

The PRECIS Caribbean project utilises collaboration to produce climate change scenarios specific to the Caribbean.

Collaborators - Round One

At the initiation of the PRECIS Caribbean Project the following countries partnered to produce the results presented in this document. The run allocation was as follows.

Cuba

50 km domain
A2, B2, baseline (1960-1990), reanalysis

Jamaica

50 km domain
A2, B2, baseline

Barbados

25 km domain
A2, B2, baseline



The PRECIS Caribbean Project

So why isn't every Caribbean meteorological service running PRECIS for its country?

Even though PRECIS is a significant step toward improving the abilities of small and developing countries to generate climate scenarios of relevance to them, running PRECIS has its challenges. It demands some expertise and experience in modelling; consumes vast amounts of storage space for each scenario run; and takes upward of 2 months or longer for one simulation, even on a fast PC. Consequently, the Hadley Centre has advocated groups of scientists in neighboring countries working together to configure the model over their own region and to run their own regional climate change predictions. By so doing the capacity and expertise also reside within the region and awareness of climate change impacts is spread far beyond that which would have been achieved by handing out results from models run in developed countries. The Caribbean has adopted exactly this approach.

With funding from the Global Environment Facility (GEF) via the Mainstreaming to Adaptation in the Caribbean (MACC) project, the Japanese Trust Fund operated by the World Bank, and coordination by both the Caribbean Community Climate Change Center (CCCCC) and INSMET the PRECIS Caribbean project has been in existence for nearly four years. It began with a workshop on PRECIS in Havana in September 2003 which was attended by scientists of varying backgrounds, (from meteorology to civil engineering). The aim of the workshop was to begin the task of producing climate change scenarios for two regional projects - the ACCC project (Adaptation to Climate Change in the Caribbean) based at the time in Barbados and a GEF/UNDP-funded project "Capacity Building for Stage II Adaptation to Climate Change in Central America, Mexico and Cuba", for which the executing agency is CATHALAC in Panama. The workshops were conducted by scientists from the UK Hadley Centre.

At that workshop the decision was taken to undertake a core set of 50 km and 25km resolution runs using the A2 and B2 SRES scenarios (See again the Box on page 5). The 50 km runs would be done over a domain which included the entire Caribbean and Central America while the 25 km runs would be done for the eastern Caribbean. Additional runs would be done to facilitate later analyses, and the runs would be produced collaboratively i.e. with different countries agreeing to run different experiments or different members of an ensemble, but using the commonly defined domains. This would facilitate an exchange of results. The participating islands are shown in the adjacent box and the participating institutions are listed at the end of the document.

In 2006, a follow up workshop sponsored by the CCCCC took place in Belize City, Belize. The first three days of the workshop were for new users of PRECIS, and the last two days were for sharing results of the first allocation of runs. The results from the first stage of the PRECIS project are presented in this document. In a real sense, this document is a testament to what can be achieved through collaboration, particularly in the sciences.

5. Future Changes in Caribbean Climate

Some results of the PRECIS Caribbean project are presented below. Only temperature and precipitation are considered and the results show the changes in seasonal and annual average values for a low (B2) and a high (A2) emission scenario. The change is derived by subtracting from the means for the 30-year period centered on the 2080s (2070-2090) the 30-year average climate for the present (1960-1990) as simulated by PRECIS. The standard climatological seasons are adopted i.e. December-January-February (DJF); March-April-May (MAM); June-July-August (JJA); and September-October-November (SON). For precipitation, results are shown as percentage change.

Temperatures

The annual warming rates vary from about 0.1°C to 0.3°C per decade for the lower emission scenario to about 0.1°C to 0.4°C for the Medium to High emission scenario (Figure 4). These rates are similar to global-average warming rates per decade. As a result the Caribbean is between 1°C and 5°C warmer in the annual mean by the 2080s depending on the region and scenario. There is no section of the Caribbean that is immune to annual warming even under the low emission scenario, and there is a pattern of the larger northwest Caribbean island territories and Belize warming more in the annual than the eastern Caribbean island chain and the other Caribbean territories of Central America. This pattern is true irrespective of emission scenario. Guyana also appears to warm as much as the northwest Caribbean as do areas on the Pacific coast of Costa Rica and Panama.

The warming in the northwest Caribbean is most pronounced from May through October and by the late summer months (June-July-August) the change over western Hispaniola, eastern Cuba, Jamaica and Belize is in excess of 3°C (4°C) for the low emission (high emission) scenario. Lowest warming rates are observed in March, April and May. There is the suggestion that places of highest elevation in the model experience greatest warming rates.

The main conclusions about changes in average temperature are:

- An annual warming by the 2080s of between 1° and 5°C depending on the region and scenario.
- Greater warming in the northwest Caribbean territories (Jamaica, Cuba, Hispaniola, Belize) than in the eastern Caribbean island chain.
- Greater warming in the summer months than in the cooler and traditionally drier earlier months of the year.

Rainfall

The patterns of change in annual average precipitation suggest a drying across the main Caribbean basin. Decreases in rainfall range from 25 to 50% depending on the region of the Caribbean and the scenario. In the annual, the southern Caribbean (the ABC islands) and the islands from St. Kitts to Martinique show the largest percentage decrease relative to baseline by the 2080s (Figure 5). The exception to the drying trend is found in the far north Caribbean including western Cuba and the southern Bahamas, and in Costa Rica and Panama. Both are up to 25% wetter under both the low and high emissions scenario.

The Caribbean will warm by 1° to 5°C in the annual mean by 2080s.

Summer warming greatest for Cuba, Jamaica and Belize.

Most of the Caribbean will be up to 25% drier in the annual mean by 2080s.

There is a regional pattern to the rainfall change.

The pattern of a wet north – dry south Caribbean is a strong feature of the early months of the year i.e. January through May, as seen from the seasonal patterns of change. During these months, however, the band of wetness extends farther south than in the annual picture and a clear north-south gradient in average annual rainfall change becomes apparent. That is, the region north of 18°N is wetter by the 2080s while those territories south of this latitude, including much of the island chain, are drier. Though this is traditionally the dry season for the Caribbean, a similar gradient in rainfall is a feature of the current climate pattern. The effect of climate change, then, is to enhance the ‘wetness’ and ‘dryness’ of established wet and dry zones, respectively, during the first four to six months of the year. Again Costa Rica is the exception with a rainfall increase expected in these earlier months. From May through October, however, the entire Caribbean is up to 25% drier with the severity of drying being worse for the high emission scenario.

The main conclusions about changes in average rainfall are:

- A drier main Caribbean basin in the annual total by the 2080s, except for western Cuba, south Bahamas, Costa Rica and Panama.
- A pronounced north-south gradient in rainfall change during the Caribbean dry season (January to April). The Caribbean north (south) of 18°N is wet (dry).
- Summer drying is more severe i.e. during the Caribbean wet season.

Sea level

In general most RCMs (including PRECIS) do not model oceans, as this would substantially increase the computing cost yet, in many cases, would make little difference to the projections over the land that most impacts assessments require. Consequently, no conclusions about sea level rise can be directly drawn from this study.

PRECIS versus the GCMs

There are very few other Regional Model studies of the Caribbean with which to compare the PRECIS results. The Caribbean is, however, included amongst 30 regions of the world for which annual and seasonal change results have been generated using 7 GCMs running the A1FI, A2, B1, and B2 scenarios. Note that in that inter-comparison study the Caribbean is treated as a whole and a single number is generated to represent the region.

There is some consistency with the GCMs results and the PRECIS Caribbean Project. All the GCMs project a warming in the region by the 2080s which similarly ranges from 1°C to 4°C dependent on scenario and model. None project cooling and by September-October-November the warming is largely between 2°C and 4°C. The rainfall projections show less agreement. Of the 24 simulations represented, however, 16 do suggest a wetter Caribbean in December-January-February, with the highest emission scenarios indicating up to 28% wetter. In June- July-August, 20 of the 24 simulations suggest a drier Caribbean (up to 60% in the most severe case). The numbers are evenly split between wet and dry for September-October-November. Data for the Caribbean from the GCM inter-comparison study can be found at:

http://ddcweb1.cru.uea.ac.uk/sres/scatter_plots/scatterplots_region.html

PRECIS can't tell us about sea level rise.

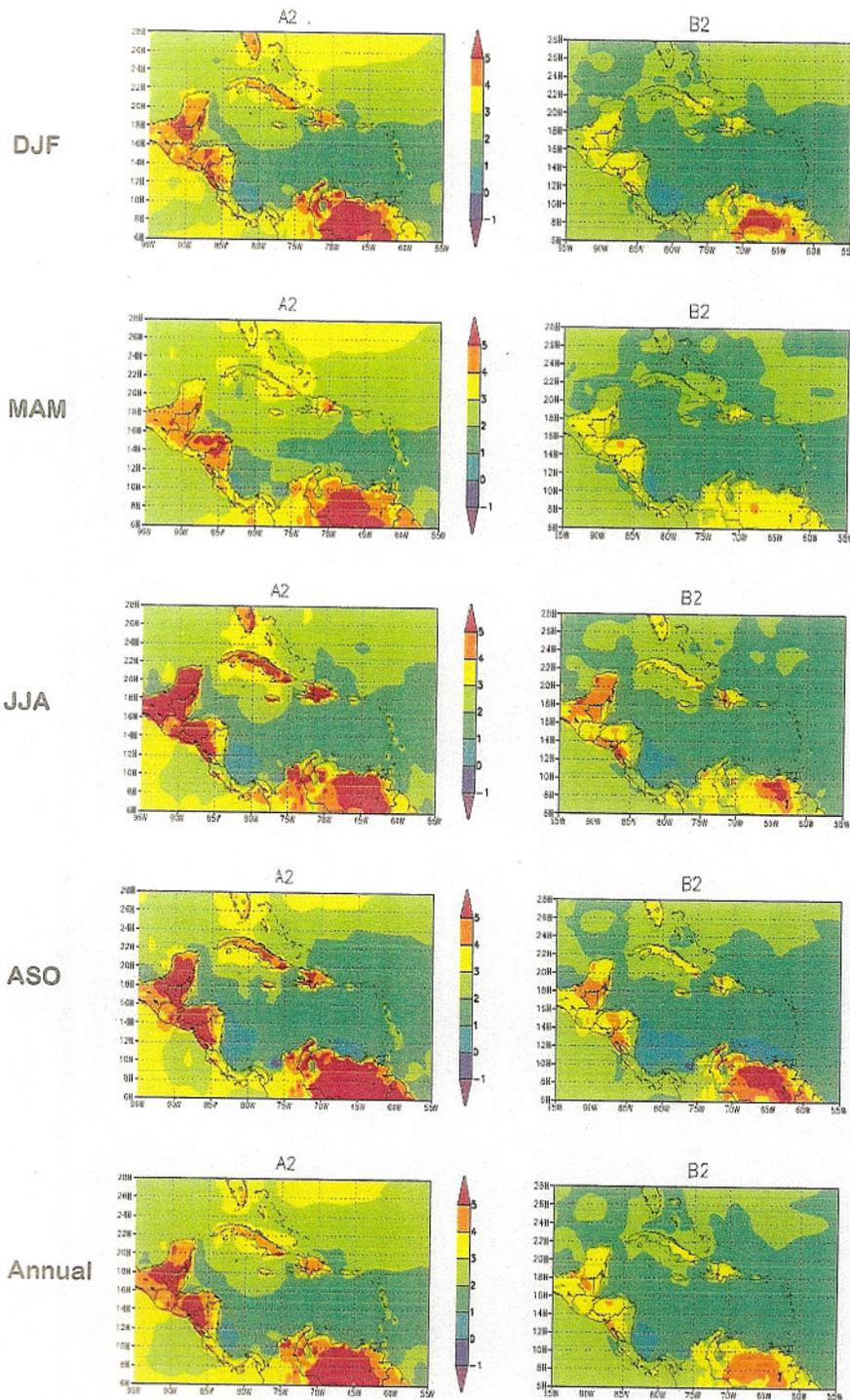
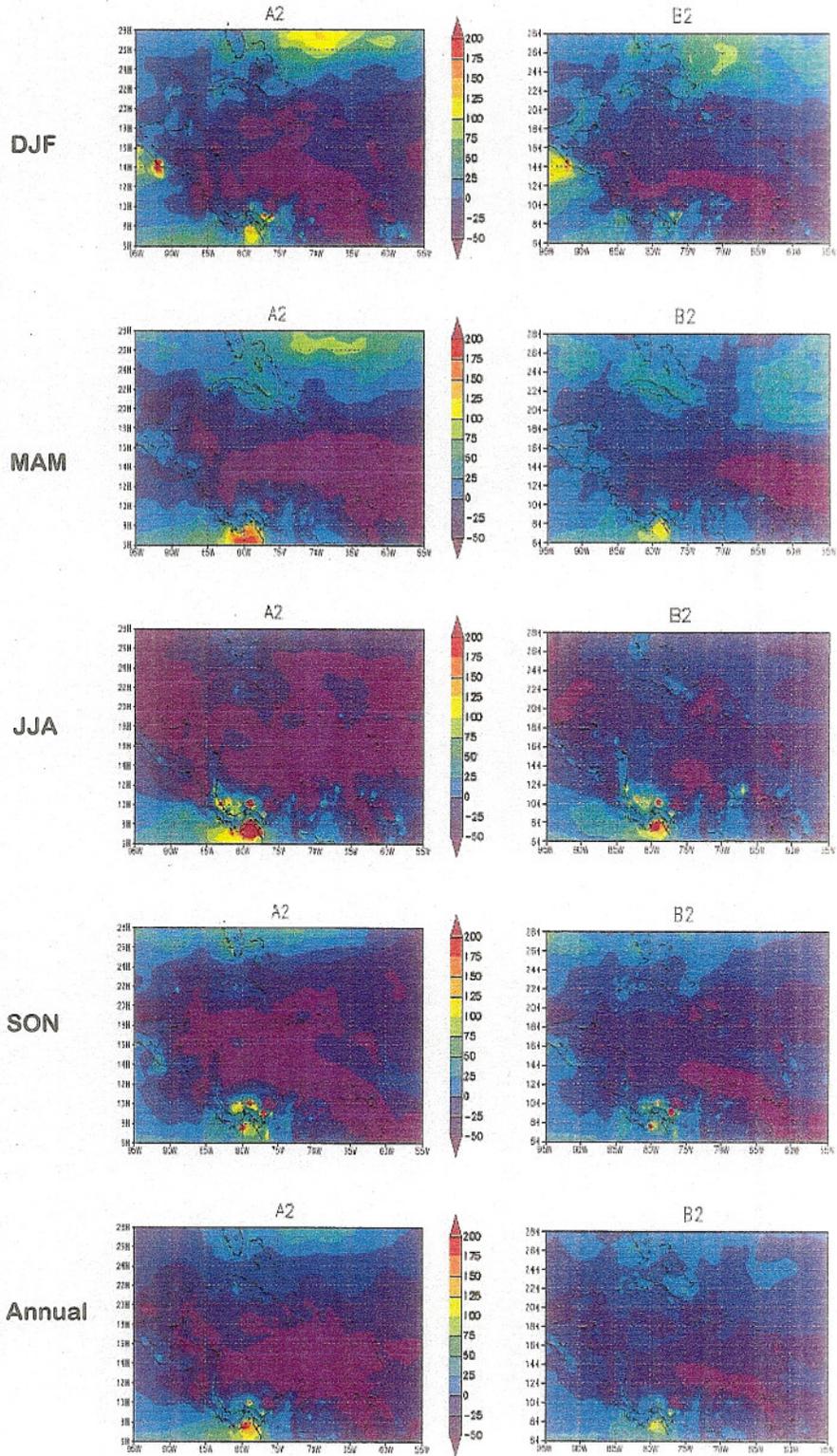


Figure 4: PRECIS simulated temperature change ($^{\circ}\text{C}$) in the Caribbean by the 2080s with respect to baseline (1960-1990). Change shown for Medium High (A2) and Low (B2) emission scenarios.

Figure 5: PRECIS simulated rainfall change (%) in the Caribbean by the 2080s with respect to baseline (1960-1990). Change shown for Medium High (A2) and Low (B2) emission scenarios.



6. Uncertainties

How certain can we be about the PRECIS results? It is hard to say how accurate the projections are, since even the near future has not yet occurred. We know that there are uncertainties in each of the main stages required to produce the scenarios, some of which can be accounted for using PRECIS and some which can't. Importantly, however, when the results of the PRECIS Caribbean Project are being utilised for assessing the impacts of climate change, these uncertainties should at least be borne in mind and where possible communicated by using a range of values for the future change. Four main sources of uncertainties are presented below.

Uncertainties in the future emissions and future concentrations

The SRES scenarios have inherent uncertainties in the assumptions they may make about relationships between future populations, socio-economic development and technology. These uncertainties have been well documented (See Appendix 2). We can account for these uncertainties in the PRECIS Caribbean project by making projections using the full range of SRES scenarios available. Results are, then, expressed as a range of possible values under low to high emission scenarios, and we can point out where consensus is being attained, as is done in Figure 6.

However, even if there were to be certainty about the amount of emissions, there would still be uncertainty in the conversion of emission to concentrations. This is due to an imperfect understanding of some of the processes and physics in the carbon cycle and chemical reactions in the atmosphere. These uncertainties are not addressed in PRECIS and would require the model to explicitly simulate the carbon cycle feedback.

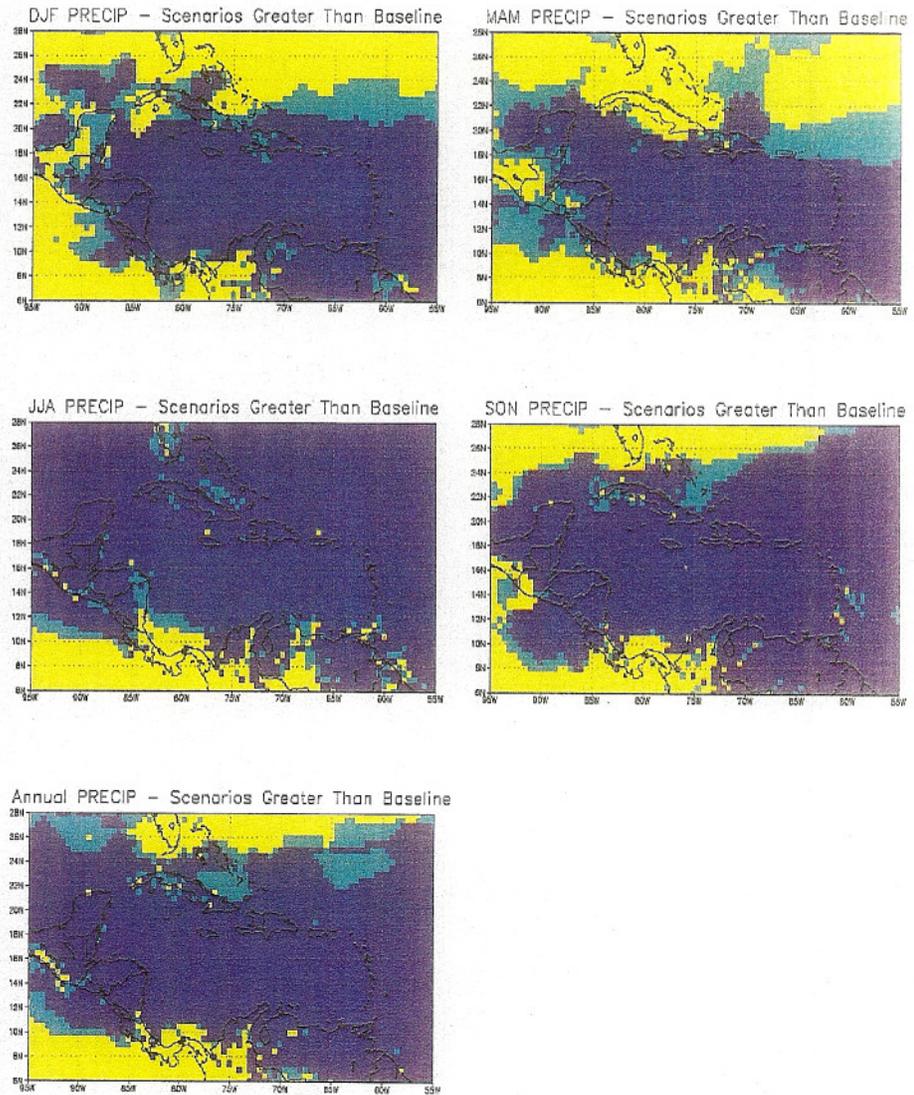
Uncertainties in the response of climate

Even the best models contain incomplete description of key processes and feedbacks occurring in the atmosphere, due to our incomplete knowledge of our climate system. This is easily seen by the fact that different GCMs project different magnitudes and patterns of climate change for a given region using the same emission scenario. One way to account for this uncertainty is to utilize different GCM projections to force the RCM and as input to climate impact studies. The results can then be expressed as a range of values as provided by different global models and use can again be made of consensus diagrams. This option was not available for use in the first stage of the PRECIS Caribbean project as only results from the Hadley Centre GCM were used to force PRECIS. Other GCM projections are, however, being incorporated in future work to be done in the ensuing stages of the modelling work in the Caribbean (See the following section).

There are inherent uncertainties in the results.

Results can be expressed as a range of values to communicate the uncertainties.

Figure 6:
Precipitation consensus diagram. Purple - grid boxes where no scenario produced a wetter Caribbean by the 2080s; blue - one scenario indicates a wetter Caribbean; yellow – both scenarios, A2 and B2 indicate a wetter Caribbean.



What About Temperatures?

The consensus diagrams for temperature suggest that irrespective of the scenario i.e. whether A2 or B2, every grid box in the domain indicates a warmer Caribbean by the 2080s.

Uncertainties due to natural variability

Climate does vary 'naturally' on timescales of years to decades and this variability can act to change the climate in the future in addition to the changes due to human activity. While the uncertainty due to natural variability cannot be removed it can be quantified and accounted for in projections such as those presented in this document. One way to do so is to remove the natural variability as can be calculated for today's climate. This, however, assumes that the variability of the future will be the same. Another option is to run ensembles of future climate projections. Each member of the ensemble is identical except that the run is initiated from a different starting point. The results of the ensemble will allow for an estimation of a range of possible futures which are likely to span the evolution of the climate system. This is facilitated in the PRECIS system, though no ensemble results are presented in this document.

Uncertainties in regional climate change

There are, finally, uncertainties inherent in the technique chosen for regionalization i.e. the process for attaining high resolution results from the coarser resolution GCMs. Different techniques yield different projections even when forced by the same GCM results. This must be borne in mind and, where possible, climate change information for any region should be communicated as a range of possible values attained from different techniques.

7. Where Do We Go From Here?

PRECIS CARIBE – An online system for accessing PRECIS output

An immediate task is getting the information out to be used by those involved in climate impact assessment work. To that end, all the results from the first round of simulations undertaken in the PRECIS Caribbean Project are available online at the PRECIS CARIBE website. PRECIS CARIBE allows members of the scientific and impact assessment community to obtain maps and numerical data from the climate projections corresponding to the different IPCC greenhouse gases emission scenarios. A brief description of the PRECIS model as well as useful links is also available.

The access mechanism is simple. After the introductory page the user is presented with a form on which the region of interest, time period, variable, pressure level and scenario can be selected (Figure 7). It is also possible to select different chart types for the output. Once the form is submitted the output is given on a new page of the browser with links to the numerical data in ASCII and Netcdf formats. Charts and data represent the change from the 1960 - 1990 baseline average (Figure 8).

To access the PRECIS CARIBE website go to: <http://precis.insmet.cu/Precis-Caribe.htm>. Future plans include modifying the layout of the web page to improve its functionality, including new features, multilingual support (English, Spanish and French) and a new design. As new outputs of the PRECIS Caribbean Project become available, the data will be added, mainly new scenarios and data for other domains with higher resolution.

Remember, PRECIS represents just one technique for attaining climate scenarios.

PRECIS data can be found on the website for PRECIS CARIBE.

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Figure 7:
PRECIS CARIBE
user input form.

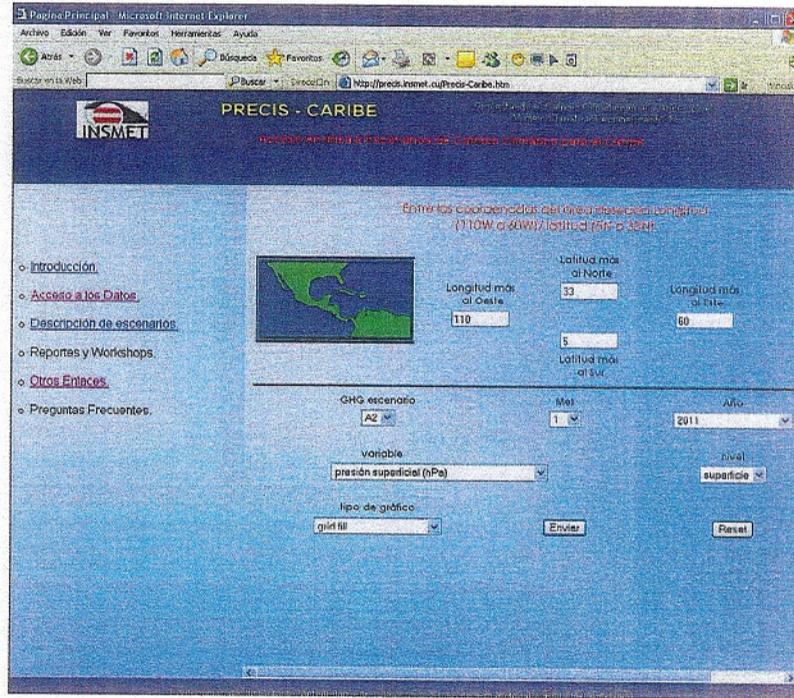
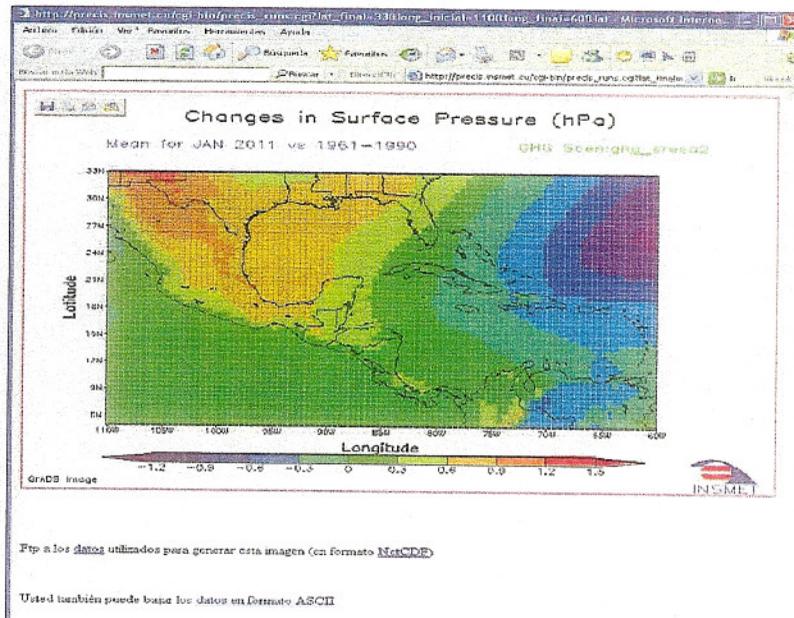
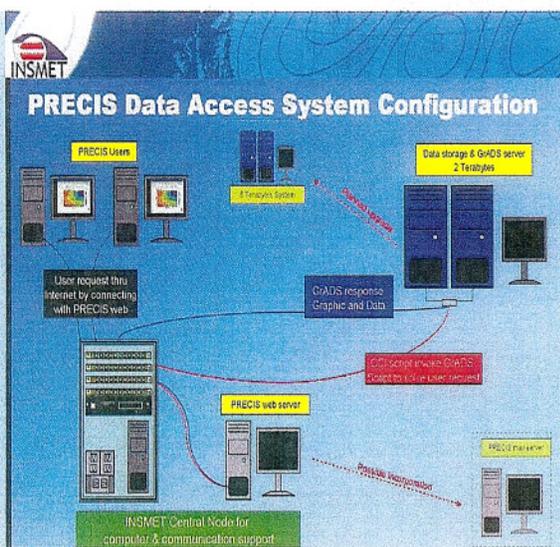


Figure 8:
Sample web output
from PRECIS
CARIBE.



Making PRECIS CARIBE possible

Outputs from the PRECIS model were converted from the original PP format into GrADS files and stored on a 2 Terabyte RAID assemble. The web server script translates the command line from the browser into a GrADS command line that produces the requested chart. The attached figure illustrates the system configuration located at the Institute of Meteorology in Cuba.



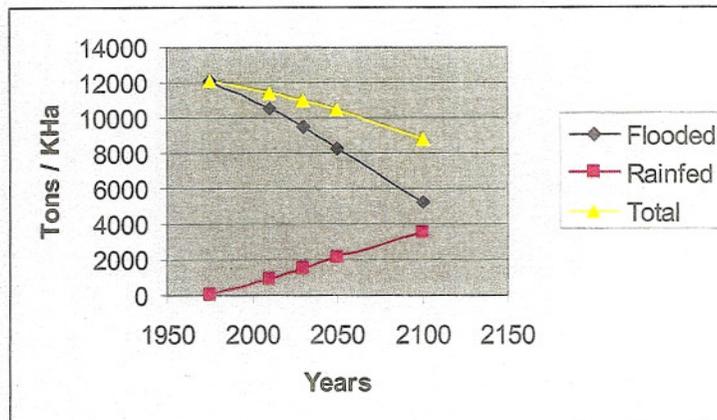
Using Climate Projection Data for Impact Assessment

A number of studies have shown that sectoral assessment of climate change impacts in Caribbean countries is possible. For example, the results from integrated impact assessment approaches in the agriculture and water resources sectors are shown in Figure 9. The results suggest that the integrated negative impact on food production would be larger than the independent impact of climate change on agricultural yields only. This kind of information is what is needed to explore adaptation options that would improve resiliency and alleviate the anticipated negative impacts.

Yet, in the example above, the climate information was derived from GCMs. The use of high resolution climate change scenarios as obtained through regional models like PRECIS will therefore significantly improve the ability to reflect what should be expected and what will be the best possible adaptation option in a given climate sensitive sector. For example, the ability will exist to distinguish between different rice production areas that were previously all embedded in one GCM grid cell. The comprehensive set of climate variables derived from PRECIS and the model's higher resolution will also allow us to use impact models of greater complexity and with better agreement with reality, thereby heightening our confidence in proposed adaptation policies. The challenge now is to make use of the data.

We must begin to use the data for integrated assessment studies.

Figure 9:
Expected flooded, rain fed and total rice production in a large sized farm enterprise in eastern Cuba. Total production reflects the result of an adaptation option to the combined negative impacts of climate change on rice yields and available irrigation water during the 21st century.



More Analysis

The first stage of the PRECIS Caribbean Project has yielded large amounts of data on which analysis has only just begun. The surface has only been scratched and there is a clear need for scientists from the region to take the data and subject it to more rigorous and extensive analysis. More scientists working on the problem will shorten the time frame in which useful information will become available and hasten the advent of the era of informed decision-making.

The possibilities for additional research are many including, for example, the analysis of extreme weather events. In the Caribbean tropical storms are one of the most important natural hazards for which planning is a must. Knowing about their behavior in the future is crucial. GCMs do not properly represent tropical storms or hurricanes. So the PRECIS system, with its higher spatial resolution, is a potential tool for addressing this need. Figure 10 clearly illustrates that PRECIS has the potential to represent cyclones. This simulated PRECIS storm is located in the eastern Gulf of Mexico and has an intensity close to a hurricane. It is also well described in the upper atmosphere. The upper panel depicts the vertical-longitudinal section of northerly and southerly winds. It is easy to appreciate that the northward (right half) and southward (left half) winds appear well represented in all the atmospheric levels. Given this, the output of PRECIS can also be coupled with other models to yield additional information such as storm surge or coastal flooding potential in the future.

More Simulations, More Models, More Data

The next stage of the PRECIS Caribbean Project is already underway. It involves more simulations using other GCM projections as input to enable an estimation of the uncertainties due to climate response. This stage will also see up to 17 additional simulations using output from the Hadley Centre GCM running the A2 scenario, but with slight alterations to some parameters in the physics package which govern atmospheric processes. This means more data will be available by the end of 2007 for analysis of regional climate change. In addition, there is a move afoot to analyse other model data sources which are available to Caribbean scientists i.e. comparing the PRECIS projections output to projections from other RCMs (e.g. RegCM3) or very high resolution GCMs. Results from the Japanese Super-High Resolution Model (at 20 km resolution) are currently being investigated. Comparisons with results from other techniques e.g. statistical downscaling, will also be done.

PRECIS can be used to analyse future changes in weather extremes such as hurricanes.

There is more work to be done.

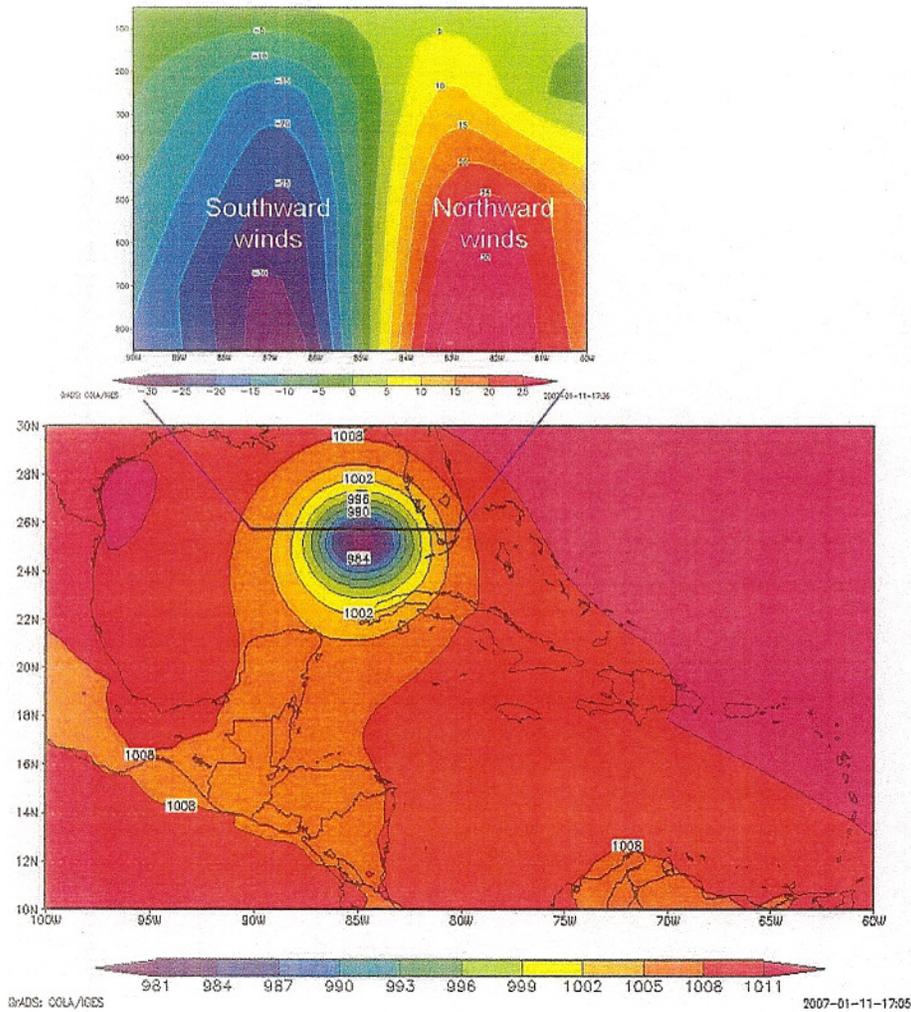


Figure 10: Surface and upper air characterization of a tropical storm in the eastern Gulf of Mexico. Bottom panel: Mean sea level pressure showing the storm's location. Top panel: Vertical longitudinal section of meridional wind component at 25°N from 90°W to 70°W

Learning the Lessons

Completing the first stage of the PRECIS Caribbean project has by no means been an easy task. The lessons learnt so far must, therefore, be taken into the future. Paramount among them is the advantages of the collaborative approach for quickly advancing the production of good and useful science. It is doubtful if any one Caribbean modelling centre would have been able to produce all the results shown in the same time. The benefits of consultation, parallel activity, encouragement, sharing and discourse should not be downplayed or underestimated. Indeed, the further advancement of the process of adequately coming to grips with climate change in the Caribbean will not stop if the collaborations cease to exist, but the collaborations will undoubtedly speed up the process. This is a lesson and model that other communities within the region would do well to adopt.

Let's work together.

Appendix 1 - Glossary of Terms

adaptation. Adjustments in ecological, social, or economic systems in response to climate change and its effects or impacts.

baseline. The thirty-year period 1961-1990, corresponding to either observed or model-simulated data. The baseline also serves as the reference period from which the modelled future change in climate is calculated.

climate change. Change in climate over time, whether due to natural variability or as a result of human activity.

climate change scenario. A climate change scenario is the difference between a climate scenario and the current climate.

climate scenario. A climate scenario is a plausible, self-consistent outcome of the future climate that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate projections, using for example simulations of future climate using climate models.

Kyoto Protocol. The Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases.

downscaling. Downscaling is the process of deriving regional climate information based on large-scale climate conditions.

GCM. General Circulation Model. A mathematical representation of the climate system based on the physical properties of its components, their interactions and feedback processes. GCM is also an acronym for Global Climate Model.

Greenhouse Effect. The trapping of heat by an envelope of naturally occurring heat-retaining gases (water vapour, CO₂, nitrous oxide (N₂O), CH₄, and ozone) that keeps the earth about 30°C (60°F) warmer than if these gases did not exist.

Greenhouse Gases. Gases in the earth's atmosphere that absorb and re-emit infrared radiation. These gases occur through both natural and human-influenced processes. The major green house gas is carbon dioxide (CO₂).

Intergovernmental Panel on Climate Change (IPCC). International forum of experts brought together by the United Nations to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and mitigation. It was formed in 1988.

mitigation. Human intervention to reduce the sources or enhance the sinks of greenhouse gases.

RCM. Regional Climate Model. A RCM is a tool to add small-scale detailed information of future climate change to the large-scale projections of a GCM. RCMs are full climate models and as such are physically based and represent most or all of the processes, interactions and feedbacks

scenario. A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of *technology* change, prices) and relationships.

storyline. The actual description of the possible future world in the scenario which can be both quantitative and qualitative.

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Participating Institutions



Instituto de Meteorología de la República de Cuba (INSMET)

The main mission of the Institute of Meteorology is to provide timely, reliable and useful weather and climate data, including projections of the current and future state of the atmosphere. This information is directed at guarding the security of the human life and reducing the loss of material goods by natural disasters of meteorological origin, and contributing directly to the well-being of the community and its sustainable development.



The University of the West Indies (UWI)

The University of the West Indies is an international institution serving the countries of the Commonwealth Caribbean. It has 3 main campuses in Jamaica (Mona), Barbados (Cave Hill) and Trinidad (St. Augustine) as well as centres in a number of other non-campus countries. Its curricula have a strong emphasis on Caribbean issues. Participation in the PRECIS Caribbean project is through the Climate Studies Group Mona (CSGM) located in the Department of Physics on the Mona campus and through the Department of Computer Science, Mathematics and Physics located on the Cave Hill campus.



Caribbean Community Climate Change Centre (CCCCC)

The Heads of Government agreed at their 21st Meeting (2000, Canouan) to establish a Caribbean Community Climate Change Centre (CCCCC). The Centre implements projects designed to prepare for and to reduce the harmful effects of climate change and sea level rise and seek ways in which the Community can benefit from any opportunities that may result from climate change. Additionally, the CCCC is intended to position the Region to maximize benefits from new and additional resources arising from the United Nations Framework Convention on Climate Change (UNFCCC).

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- The support from the World Bank through the Japanese Trust Fund and the Global Environment Facility (GEF) through the Mainstreaming to Adaptation in the Caribbean (MACC) project.
- The support from the GEF through the Capacity Building for Stage II Adaptation to Climate Change in Central America, Mexico and Cuba.

Where to find more information on....

Caribbean Community Climate Change Centre (CCCCC)	http://www.caribbeanclimate.bz
Climate Studies Group Mona (CSGM)	http://mona.uwi.edu/physics/Research/csg/index.htm
Institute of Meteorology in Cuba (INSMET)	http://www.insmet.cu
Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report	http://www.grida.no/climate/ipcc_tar/index.htm
PRECIS	http://precis.metoffice.com/index.html
PRECIS -CARIBE	http://precis.insmet.cu/Precis-Caribe.htm
Special Report on Emissions Scenarios (SRES)	http://sres.ciesin.org http://www.grida.no/climate/ipcc/emission/ http://climatechange.unep.net/jcm/doc/emit/sres.html
Global Climate Models (GCMs) and Regional Climate Models (RCMs)	http://www.metoffice.gov.uk/research/hadleycentre/models http://precis.metoffice.com/docs/PRECIS_Handbook.pdf
Impacts and Vulnerability Assessments	http://www.grida.no/climate/ipcc_tar/wg2/index.htm http://www.ipcc.ch/pub/sr97.htm
UWI	http://www.uwi.edu/default.aspx

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