APN CAPaBLE

- Making a Difference –

Scientific Capacity Building & Enhancement for Sustainable Development in Developing Countries

Enhancement of National Capacities in the Application of Simulation Models for the Assessment of Climate Change and its Impacts on Water Resources and Food and Agricultural Production

Final Report for APN CAPaBLE Project: 2005-CRP1CMY-Khan

DHM, Nepal | GCISC, Pakistan | PMD, Pakistan | BUP, Bangladesh

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Pakistan Meteorological Department (PMD), Islamabad, Pakistan
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Overview of project work and outcomes

Non-technical summary

This was one of the first two comprehensive capacity building cum research projects of 3 years duration awarded by APN under its CAPaBLE programme, which was launched in 2003. The project, which concluded on 31 August 2007, has played an effective role in enhancing the capacities of Bangladesh, Nepal and Pakistan in the area of simulation modelling for Climate Change (CC) research. It helped to impart training to a total of 99 scientists from the three beneficiary countries (Bangladesh, Nepal and Pakistan) in the fields of Regional climate modelling (RCM), Watershed simulation modelling (WSM), Crop simulation modelling (CSM), and Development of regional CC scenarios, with a minimum of 4 persons from each country benefiting from each of the 4 training activities conducted for this purpose. This enhanced capacity was effectively utilised to varying extent by the three countries to pursue envisaged research on (i) implementation, validation and calibration of a variety of RCMs, WSMs and CSMs, (ii) development of coarse and fine resolution CC scenarios for the three countries, (iii) assessment of the impacts of expected CC on annual and seasonal flows of their main rivers and on the yields of major crops in different agro-climatic zones, and (iv) identification and evaluation of appropriate adaptation measures and coping mechanisms to counter the negative impacts of CC. Two regional workshops were held during the last 3 months of the project tenure to discuss the research results and to review and harmonize the draft technical reports. Unfortuntely the scientists from Bangladesh could not participate in these two regional activities due to some unforeseen difficulties. In the last two weeks of the project tenure, 2 national level seminars were held, one in Kathmandu and the other in Islamabad, to brief the national planners and policymakers in Nepal and Pakistan about the capacity building achievements and research findings of the project. The chief guests at both these seminars were the respective heads of National Planning Commissions, while the audience comprised senior and middle level professionals from various relevant ministries, government departments, NGOs and international organizations. The project outcomes were much appreciated by the heads of the Planning Commissions in Nepal and Pakistan, who emphasized that this type of research is highly relevant to the countries of the South Asia region whose Water Security and Food Security are at great risks due to global climate change.

Objectives

The present project aimed to:

- Enhance Climate Change (CC)-related research capacity of the beneficiary countries (Bangladesh, Nepal and Pakistan) in areas of Regional Climate Modelling (RCM), Watershed Simulation Modelling (WSM) and Crop Simulation Modelling (CSM);
- Make use of the enhanced capacity to (i) formulate country specific plausible CC scenarios, (ii) assess the corresponding impacts on water resources and agricultural production, and (iii) identify appropriate adaptation measures to cope with the adverse impacts;
- Disseminate the research results to national planners and policy makers; and
- Provide useful inputs to IPCC Assessment Reports.

Amount received and number of years supported

The Grant awarded to this project was: US$ 120,000 for Year-1; US$ 90,000 for Year-2 and US$ 90,000 for Year-3.

Work undertaken

a) Organisation of Regional Workshops:

i. 4 Regional Capacity Building Workshops were held;

ii. 2 Regional Workshops were held for Discussion and Harmonisation of Research Results.

b) Organisation of National Seminars

i. Briefing Seminars were held for National Planners and Policymakers (Participants: 240 in Pakistan; 112 in Nepal)

c) Research Work:

i. Testing, selection, validation and calibration of various Simulation Models: RCMs, WSMs and CSMs for CC research;
ii. Assessment of the CC trends in various parts of Bangladesh, Nepal and Pakistan over the last 3 to 5 decades by analysing the available meteorological data;
iii. Formulation of CC projections to the year 2100 for Bangladesh, Nepal and Pakistan, each, and for large sub-regions of Pakistan, based on the coarse resolution (about 300 km X 300 km) outputs of an ensemble of Global Circulation Models (GCMs) corresponding to selected IPCC scenarios;
iv. Development of high resolution (50 km X 50 km) CC scenarios for each of the participating countries by dynamic downscaling of the available GCM outputs for selected IPCC scenarios using the Regional Climate Models RegCM3 and PRECIS;
v. Assessment of the impacts of projected CC on the yields of wheat, rice and maize crops in different agro-climatic zones of the participating countries;
vi. Assessment of the impacts of CC on the annual and seasonal flows of the main rivers of each participating country; and
vii. Identification and evaluation of the appropriate adaptation measures and coping mechanisms to counter the negative impacts of CC in the Agriculture and water sectors.

<u>RESULTS</u>

a) Capacity Building

The following Simulation Models were acquired, implemented, validated, and calibrated by the beneficiary countries and are now being used by them (the origins of the models and the user countries are shown in parentheses; BD = Bangladesh; Nep= Nepal; Pak = Pakistan):

i. Regional Climate Models (RCMs):

- RegCM3 (Int. Centre for Theo. Physics, ICTP, Italy); (Users: Pak, Nep, BD)
- PRECIS (Hadley Centre, British Met Office, UK); (Users: Pak, Nep)
- MM5 and WRF (National Center for Atmospheric Research, NCAR, USA); (User: Pak)

ii. Watershed Simulation Models (WSMs):

- DHSVM (University of Washington, USA); (Users: Pak, Nep, BD)
- UBC (University of British Columbia, Canada); (User: Pak)
- HEC-HMS (US Corps of Army Engineers, USA); (Users: Pak, Nep, BD)
- BTOPMC (University of Yamanashi, Japan); (User: Nep)
- HFAM (Hydrocomp Inc., USA); (User: Nep)
- WatBal (D.N. Yates, Int. J. Water Res. Dev., Vol. 12, p. 121, 1996); (User: Nep)

iii. Crop Simulation Models (CSMs):

- DSSAT (University of Georgia, Griffin, USA); (Users: Pak, Nep, BD)
  DSSAT comprises the following component models:
  - CERES family of models for cereals
  - CROPGRO family of models for grain legumes
  - CROPSIM family of models for root crops
  - Individual models for other crops (Tomato, Sunflower,
  - Sugarcane, Pasture)

Based on a part of the above capacity building, 3 young scientists (Bangladesh: 2;

Pakistan: 1) made use of the regional climate model RegCM3 in their research work that was submitted as partial requirements of their M. Phil/ M.S. degrees.

b) Research

Research activities were initiated and pursued in each beneficiary country on the main themes listed above in Section titled "**Work undertaken**" under its Sub-Section (c): "**Research Work**". Several of these activities are on-going and will continue over the foreseeable future. For the output of this research effort during the tenure of the project, please see below the section titled **Publications**.

Relevance to the APN CAPaBLE Programme and its Objectives

The project was very much in line with the three objectives of the CAPaBLE programme. Firstly, it helped capacity building of young scientists and capacity enhancement of leading researchers in the three participating countries to make use of simulation modelling techniques to conduct systematic scientific studies of the regional level climate change, its impacts on two key sectors Water and Food, and adaptation opportunities (in line with the first two CAPaBLE project objectives). Secondly, by disseminating the outcomes of the research activities to policy-makers and civil society in Pakistan and Nepal, the project (in line with the third CAPaBLE project objective) did contribute towards Improvement of informed decision-making in these two countries.

Self evaluation

Except for a setback in Bangladesh in Year-3, the project has satisfactorily met all its objectives. The envisaged 4 capacity building regional workshops on Regional Climate Modeling, Crop simulation Modeling, Watershed Modeling, and Climate Scenario Development for Impact Studies were successfully organized during the first two years of the project. At least 4 persons from each of the three participating countries attended these workshops and actively participated in the training, discussion and presentation sessions (please see the Workshop Proceedings in the CD). On return to their home countries, these trainees successfully implemented, tested, calibrated, validated and put to use the various simulation models in their respective organisations. Every thing went smoothly until the end of Year-2 when, partly because most of the project's trained personnel from Bangladesh reportedly went abroad for higher studies, and partly because the Bangladesh national team leader changed his organizational affiliation, the progress of the Bangladesh team suffered heavily. This explains why the project did not make a full impact on Bangladesh. As the research findings presented in the Technical Report and the scientific publications and conference contributions listed therein show, the project made an impressive impact on both the capacity building and the research effort of Pakistan and Nepal in the area of climate change. The two briefing seminars for national planners and policymakers held in the last month of the project tenure (August 2007), in Nepal and Pakistan under the chairmanship of the respective heads of National Planning Commissions, also contributed to the success of this project. On the whole, we therefore consider this project a great success.

Potential for further work

The participating institutions and scientists of this project may now build upon the solid foundation laid through the project in the following manner:

i. Finalise the research work already done and that in progress and publish it in international journals of repute as soon as possible; also finalise detailed technical reports, and publish and widely disseminate them to help other national institutions and scientists to benefit from this effort;
ii. Develop capability to make necessary alterations and modifications in the scientific logic and structure of the available simulation models so that they become more responsive to the local or regional conditions;
iii. Develop capability to take advantage of the recent advancements in modelling

techniques which could lead to reliable predictions at inter-decadal, inter-annual and seasonal levels, these time scales being of particular interest to most stakeholders;

iv. Extend the scope of research to address some other important impacts of climate change e.g. those on glaciers, human health, deforestation, land degradation and desertification, loss of biodiversity, intrusion of sea water in deltaic regions etc.;

v. Use the technical base developed by the project to establish collaborative scientific links with relevant international and regional organizations in the South Asia region.

Publications (For details see Appendices II-IV in Technical Report)

The work has already resulted in the publication of 2 monographs, 4 research papers in international journals/books (with 5 more submitted), 3 papers in national journals (with 1 more submitted), 8 workshop proceedings and 21 draft reports. Besides, 71 research papers were presented at various international conferences and 21 at national level conferences. A website (http://www.gcisc.org.pk) has been developed.

Acknowledgments

Our sincere thanks are due: (1) to Dr. Ishfaq Ahmad, Special Advisor to the Prime Minister of Pakistan and President, Pakistan Academy of Science, for initiating climate change research in Pakistan by establishing GCISC in 2002 and for taking keen interest in the progress of this project throughout its tenure, and (2) to Dr. Amir Muhammad, Rector, National University of Computer and Emerging Sciences and Member, SPG of APN, for introducing us to APN activities and for providing valuable advice from the inception to the completion of this project. Our thanks are also due to ICTP, CSIRO, UGG, various collaborating institutions from Pakistan, Bangladesh and Nepal, and all the project's participating scientists and resource persons for their valuable contributions to and support for this project. Finally, we are thankful to APN for the award of this project which has played a pivotal role in enhancing and building the scientific capacity of Pakistan, Nepal and Bangladesh for climate change research.

Technical Report

Preface

Until recently a major weakness of Pakistan and other South Asian countries in the field of climate change research has been their lack of expertise and experience in the area of simulation modelling. GCISC and its collaborating partners PMD, DHM and BUP were very fortunate to win one of the first two long term projects awarded by APN under its CAPaBLE program. This project has played a key role in making the scientists from Pakistan, Nepal and Bangladesh active members of the world community of climate change researchers. This report summarises the work done and results achieved under this project.

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1. INTRODUCTION

Climate change resulting from the global warming associated with the increasing concentration of Greenhouse Gases (GHG) in the atmosphere is a major worldwide concern. The IPCC Third Assessment Report (IPCC, 2001) projected that, over the period 1990 to 2100, the average global temperature would increase by 1.4 to 5.8 ^{0}C and would be accompanied by substantial changes in average global precipitation, and increase in frequency and intensity of extreme events (floods, droughts, cyclones etc). These climatic changes are likely to have very significant, often adverse, impacts on various socio-economic sectors (e.g. Water resources, Agriculture, Forestry, Biodiversity, Human Health etc.) in different world regions. Experiments based on Global Circulation Models (GCMs) suggest that global warming might alter the Monsoon pattern in the South Asia region. Besides, higher temperatures are expected in both summer and winter months, accompanied by altered yearly distribution of precipitation, including prolonged dry spells in one part and the occurrence of flood disasters in another part of the region. For example, the Indo-Pak sub-continent experienced severe drought during the period from 1999 to 2001. Similarly, Bangladesh was worst hit by a violent tropical cyclone in 1970 that cost 300,000 lives. Similar cyclones, even with an improved warning system, resulted in the loss of 13,000 and 200 lives in 1992 and 1994 respectively. The glacial melt and the receding glaciers in the Himalayas often resulting in glacial lake outbursts make a worrisome issue for countries in the region.

It is therefore of paramount importance for each country of the South Asia region to make realistic assessments of (i) the future climatic changes that are expected to occur in its various sub regions in consonance with the projected level of changes in the global climate and (ii) the likely adverse impacts of these climatic changes on the country's main socio-economic sectors. Only then will it be possible for the national planners to identify and adopt appropriate adaptation measures and guide the country along the path of sustainable development.

While confidence in the ability of computer models to project future climate has increased substantially during the past decade with the availability of much improved versions of large scale GCMs capable of representing extremely complex physical processes, these sophisticated global models are still found to be very much lacking in their ability to capture location-specific climatic, physical, and socio-economic variations because of their poor spatial resolution. A major improvement in recent years has been the development of techniques to allow regional scale climate to be modelled using the GCM output. For example, the Regional Climate Models (RCMs) developed by Hadley Centre, UK and International Centre for Theoretical Physics (ICTP), Italy have resolution of 30-50 km as compared to typically 300 km resolution for a GCM. This allows scientists to project how climate change may vary among different sub regions within a large region, depending on the local topography and land use features.

The motive for the current project was the realization that the biggest weakness of most of the South Asian countries in the area of climate change research is the lack of expertise and experience in the development and use of mathematical models for assessment of the impact of global climate change on the climate of their respective country and its sub regions and the corresponding impacts on various socio-economic sectors. In fact it is due to this weakness that these countries have so far not been able to make much headway in the area of climate change research. The present project was therefore designed with a strong capacity enhancement element for understanding the operation, use and validation of mathematical models for climate change research. The project was implemented in three South Asian countries: Bangladesh, Nepal and Pakistan. These countries have a great similarity and commonality with respect to the sources of surface water and agro-climatic conditions. Because of their geographic locations, these countries can also be simultaneously covered in the model runs based on RCMs for which the study domains are typically of size 5000 km x 5000 km.

1.1 Major Objectives

i. (a) Enhancement of national capacities in the operation and use of Regional Climate Models (RCMs) such as RegCM (of ICTP, Trieste, Italy) and PRECIS (of Hadley Centre, UK) and in the interpretation of the model outputs; (b) formulation of climate change scenarios for the participating countries of the region using the available outputs from an ensemble of GCMs as well as by dynamic downscaling of GCM outputs with the help of RCMs and (c) initiation of RCM based collaborative research with international organizations.

ii. (a) Enhancement of national capacities for the adaptation, validation and use of appropriate Watershed Simulation Models (WSMs) (e.g., Distributed Hydrology Soil & Vegetation Model, DHSVM, developed by University of Washington and Pacific North-West National Laboratory, and UBC Watershed Model developed by University of British Columbia), and (b) research on the impacts of climate change on river inflows.

iii. (a) Enhancement of the analytical capabilities of participating research institutions in the validation, operation and use of Crop Simulation Models (CSMs) (e.g. CERES, CROPGROW and CROPSIM families of models); and (b) research on the impact of climate change on the yields of major crops using the selected crop simulation models.

iv. Research on identification and evaluation of appropriate adaptation measures to address the adverse impacts of climate change on water resources and agriculture sectors of the participating countries.

v. Holding of national and regional training courses, workshops and seminars for capacity building/enhancement, exchange of information, and dissemination of the research results of the project to national policy makers and scientists of relevant institutions.

vi. Presenting the research findings in various international and national forums and publishing them in international and national journals and as technical reports, thereby providing useful inputs to future IPCC Assessment reports.

1.2. Partner Institutions and Team Leaders

a. <u>Developing Countries</u>

Pakistan:

1. Global Change Impact Studies Centre (GCISC), Islamabad.
   (*Principal Investigator*: Dr. Arshad Muhammad Khan, Executive Director, GCISC)
2. Pakistan Meteorological Department (PMD), Islamabad.
   (*Co-Principal Investigator*: Dr. Qamar uz Zaman Chaudhry, Director General, PMD)
3. Water and Power Development Authority (WAPDA), Lahore.
4. National Agriculture Research Centre (NARC), Islamabad.
5. University of Agriculture, Faisalabad.
6. University of Arid agriculture, Rawalpindi.
7. Pakistan Institute of Nuclear Science & Technology, Islamabad.

Nepal:

1. Department of Hydrology and Meteorology (DHM), Kathmandu.
   (*National Team Leader:* Dr. Madan Lal Shrestha, Director General, DHM)
2. Nepal Agricultural Research Council, Lalitpur/ Kathmandu.
3. Tribhavan University, Nepal

4. Institute of Engineering , Lalitpur.

Bangladesh:

1. Bangladesh Unnayan Parishad (BUP)
   (*National Team Leader:* Dr. Ahsan Uddin Ahmed, Executive Director, BUP)
2. Bangladesh Meteorological Department, Dhaka.
3. SAARC Meteorological Research centre, Dhaka.
4. Bangladesh Agricultural Research Council, Dhaka
5. Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur.
6. Bangladesh University of Engineering & Technology, Dhaka.
7. Dhaka University, Dhaka.
8. Centre for Environment & Geographic information Service, Dhaka.
9. Institute of Water Modeling, Dhaka.
10. Water Resources Planning Organization, Dhaka.
11. Directorate of Planning BWDB, Dhaka.

b. <u>Developed Countries/International Organisations</u>

Australia:
CSIRO, Australia.
(Dr. Shahbaz Khan, Research Manager, CSIRO Land and Water)

USA:
University of Georgia, Griffin (UGG). Georgia.
(Dr. Gerrit Hoogenboom, Professor & Coordinator of Research, Extension and Instruction, Department of Biological and Agricultural Engineering)

ICTP, Trieste, Italy:
(Dr. Filippo Giorgi, Head, Physics of Weather and Climate Section)

1.3. Amount awarded and number of years supported

The Grant awarded to this project was:

- US$ 120,000 for Year1, 2003-2004;
- US$ 90,000 for Year2, 2004-2005; and
- US$ 90,000 for Year3, 2005-2006.

2. METHODOLOGY

2.1. Overall Approach

The overall methodology of the project consisted of the following elements as shown in Figure 1:

i. Capacity building/ enhancement in the field of Simulation Modelling;
ii. Analysis of Historical Data;
iii. Research, in particular that based on the capacity enhancement sought through the project; and
iv. Dissemination of research results.

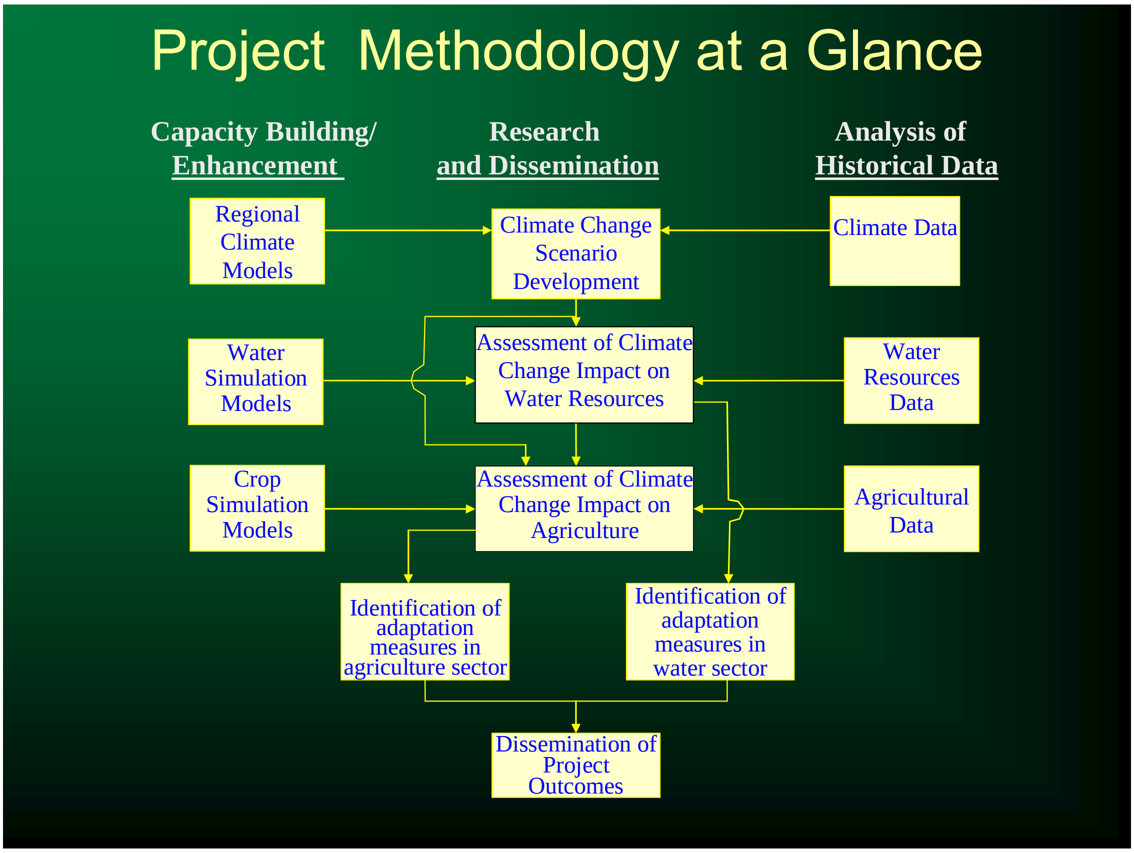

Figure 1: A simplified graphical representation of the project methodology

The focus of this effort was in 3 areas in relation to climate change and its impacts:

1. Climatology
2. Agriculture
3. Water Resources

The project sought (a) to enhance the capacity of the participating developing countries in the application of simulation modelling in each of the above areas and (b) to make use of the enhanced capacity for research work leading to: (i) development of fine resolution climate change scenarios for each country, in line with the IPCC global scenarios, (ii) assessment of the corresponding impacts on the water resources and food and agricultural production, and (iii) identification and evaluation of appropriate adaptation measures. The flow of information in the methodological approach adopted for use in the research work under this project is outlined in Figure 2. The starting point is a coarse resolution (typically 300 km X 300 km) GCM output from a supercomputer representing the global climate scenario corresponding to an IPCC SRES scenario (IPCC, 2000). A part of this information corresponding to a selected domain (typically 5,000 km X 5,000 km) is then fed as input, together with fine resolution land cover and topographic data for the domain, to an RCM operating on a Pentium-4 PC. The RCM output provides fine resolution (typically 50 km X 50 km) climate scenario for the domain under study. The climate change scenario is then obtained by comparing the average climate scenario for a future period (typically a 30 year time slab) with the model simulated average climate for the base year period (1961-1990 in the present studies). This data is then subjected to detailed analysis of various climatic parameters (on annual, seasonal and monthly basis) to obtain climate change scenarios for different sub regions (countries or parts of countries).

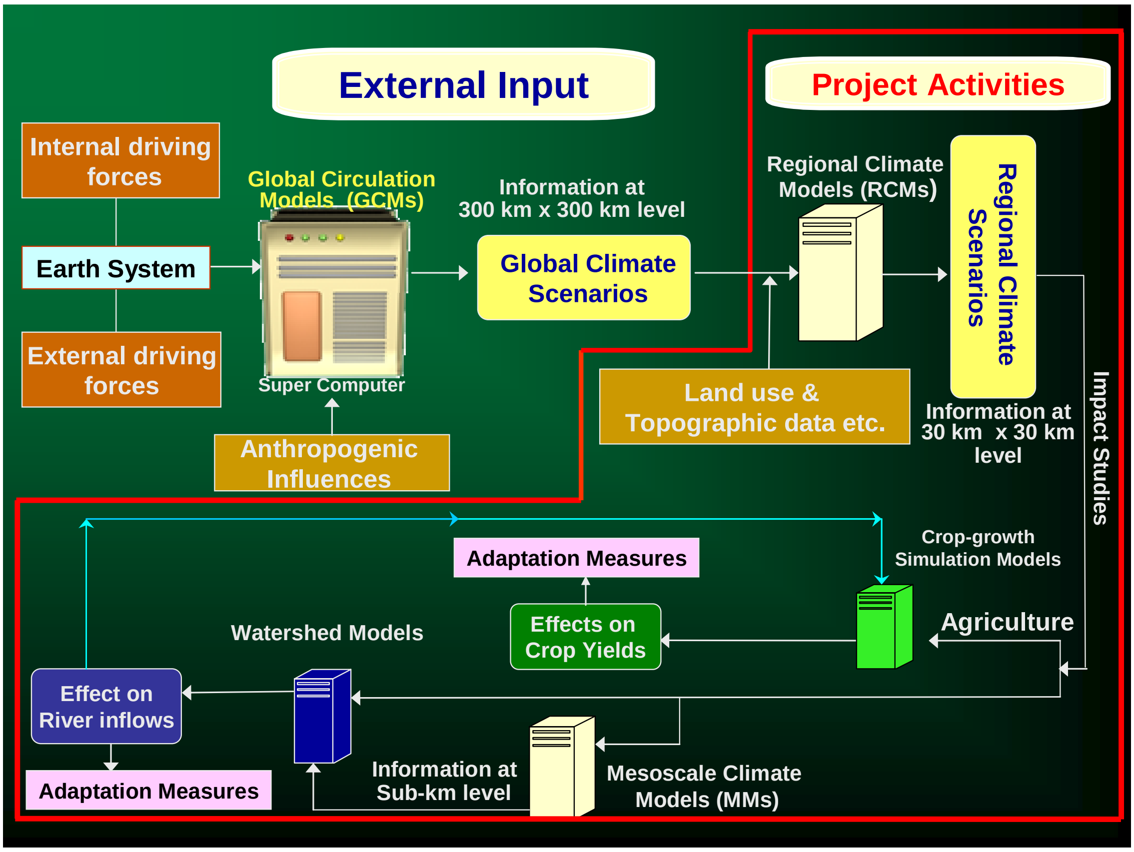

Figure 2: Flow of information in the project's methodological approach

The RCM based climate change scenario is then used (i) in combination with a WSM, to assess the impact of climate change on river flows, and (ii) in combination with a CSM, to assess the corresponding impacts on yields of selected agricultural crops, in particular cereal crops. Even higher resolution climate change information (1 km X 1 km or better), if required for simulating the watershed behaviour, may be obtained by processing the RCM output further with the help of a mesoscale model such as MM5 and WRF developed by the National Centre for Atmospheric Research (NCAR) in the U.S. The CSM may also make use of the information obtained from WSM to evaluate the combined effect of the changes in climatic parameters and the change in irrigation water availability, if any, caused by the change in river flow patterns. An effort is then made to identify and evaluate (generally using WSM and/or CSM) different potential adaptation measures with a view to minimise the negative impacts of climate change on water resources and crop yields.

2.2 Capacity Building Activities

The following effort on capacity building/ enhancement in the three countries was undertaken during the course of this project:

2.2.1. Climatology

(i) A training workshop on Regional Climate Modelling was held at Islamabad, Pakistan from 16-27 February 2004. It was attended by 26 participants (Pakistan: 14, Nepal: 6, Bangladesh: 6) and 5 resource persons (ICTP: 4, Pakistan: 1). The ICTP resource persons were led by Prof. Flippo Giorgi, Head of the Physics of Weather and Climate (PWC) section at Abdus Salam International Centre for Theoretical Physics(ICTP), Trieste, Italy. ICTP also covered the cost of 2 of its resource persons. The workshop concentrated on imparting training in the operation and use of the regional climate model RegCM3 (Regional Climate Model version 3), which has been developed by the ICTP-PWC and is the third generation version of RegCM originally developed at the National Centre for Atmospheric Research (NCAR), USA. The ICTP scientists have continued active interaction with the project team members throughout the course of this project. (see Appendix I, and the CD for full Proceedings.)

(ii) Another training workshop on Regional Climate Scenarios for South Asia was held at Kathmandu, Nepal from 15-19 August 2005. It was attended by 24 participants (Pakistan: 8, Nepal: 12, Bangladesh: 4) and 3 resource persons (ICTP: 2, China: 1). This workshop was directed towards improving the skills of the participants in developing climate change scenarios with the help of RCMs. (see Appendix I and the CD for full Proceedings.)

(iii) Besides RegCM3 of ICTP, another RCM, PRECIS (Providing Regional Climate for Impact Studies), developed by the Hadley Centre, UK) was acquired, implemented and put to use by GCISC, Pakistan DHM, Nepal and BUP, Bangladesh by getting some of their scientists (GCISC: 3, DHM: 1, BUP: 1) trained in PRECIS Training Workshops held in Bhutan and Turkey, using their own resources.

(iv) Two mesoscale climate models (MM5 and WRF developed by NCAR, USA) have also been acquired and implemented by GCISC, Pakistan. GCISC got one of its scientists trained at a WRF Training Workshop held in USA.

2.2.2. Climate Change Impacts on Agriculture

A training workshop on Crop Simulation Modelling was organised at Chiang Mai University in Thailand from 28 June – 9 July, 2004. It was attended by 21 participants (Pakistan: 9, Nepal: 6, Bangladesh: 6) and 2 resource persons (USA: 1, Thailand: 1). The workshop provided training in the use of various families of CSMs (CERES for cereals, CROPGRO for grain legumes and CROPSIM for root crops) and individual CSMs (for tomato, sunflower, sugarcane and pasture), all operating under the environment of a Windows-based data handling set up, DSSAT (Data Support System for Agrotechnology Transfer), developed at the University of Georgia, Griffin in the U.S. The workshop was led by Dr. Gerrit Hoogenboom, Professor & Coordinator of Research, Extension and Instruction, Department of Biological and Agricultural Engineering, University of Georgia. (see Appendix I and the CD for full Proceedings.)

2.2.3. Climate Change Impacts on Water Resources

(i) A training workshop on Watershed Simulation Modelling held at Islamabad, Pakistan from 7-18 March 2005 provided training to 28 participants (Pakistan: 18, Nepal: 5, Bangladesh: 5) in the operation and application of 3 different WSMs. This workshop was led by Dr. Shahbaz Khan, Research Manager, CSIRO Land and Water CSIRO, Australia and Dr. Shahzad Jehangir, Deputy Inspector General of Forests, Ministry of Environment, Pakistan, supported by two other resource persons from GCISC, Pakistan. The WSMs covered in this workshop were: (1) DHSVM (Distributed Hydrology, Soil & Vegetation Model, developed by the University of Washington and Pacific North-West National Laboratory, USA, (2) UBC (Hydrological model developed by the University of British Columbia, Canada), and (3) HEC-HMS (Hydrologic Modelling System developed by Hydrologic Engineering Center, US Army Corps of Engineers). (see Appendix I and the CD for full Proceedings.)

(ii) Besides the above, the following 3 WSMs have been acquired, implemented and put to use by the DHM, Nepal scientists: (1) BTOPMC (a hydrological model being developed by University of Yamanashi, Japan), (2) HFAM (Hydrocomp Forecast and Analysis Modelling distributed by Hydrocomp Inc., USA), and (3) WatBal (a water balance model described by D.N. Yates, Int. J. Water Res. Dev., Vol. 12, p. 121, 1996).

(iii) GCISC (Pakistan) got three of its young scientists trained at National Agriculture Research Centre, Islamabad in the application of GIS and Remote Sensing Techniques for measuring glacier dimensions and land use changes using satellite imagery.

2.3. Research Activities

2.3.1. Climatology

2.3.1.1. Analysis of Historical Data

(a) Data Used

Pakistan: Mean monthly meteorological data for Precipitation, Maximum Temperature and Minimum Temperature for the 50-year period 1951-2000 covering 54 meteorological stations, obtained from Pakistan Meteorological Department was used. The data for only those stations was accepted where missing values did not exceed the permissible limit of 20%.

Nepal: In view of limitations on the availability of homogenous time series data of sufficient lengths, DHM, Nepal used mean monthly data for maximum and minimum temperatures from 1975 to 2005 for 20 stations and mean precipitation data from 1971 to 2005 for 67 stations out of a total of 68 Climatological stations and 337 Precipitation stations in operation in recent years.

Bangladesh: Mean monthly meteorological data for maximum and minimum temperatures and precipitation for the period 1951-2000 for various stations obtained from Bangladesh Meteorological Department was used in the analysis. Data from at least 24 stations was used for analysing the climatic trends of different parameters.

(b) Data Analysis

Statistical data analysis involving the Least Square Regression method has been used to work out the past climatic trends for temperature and precipitation at various stations on annual as well as seasonal basis. The climatic extremes (for both temperature and precipitation) were identified and their trends over the study periods were analysed. (For more information, please see Draft Reports DR-1 and NDR-4 listed in Appendix IV and provided in the CD.)

2.3.1.2. GCM Ensemble Based Climate Change Scenario Formulation

The IPCC Data Distribution Centre (IPCC-DDC) provides monthly averaged output data at

6-hourly intervals from the computer simulation experiments performed by various research centres in advanced countries on supercomputers using their respective coupled atmosphere-ocean GCMS (AOGCM) to obtain global climate projections until the end of the 21st century, corresponding to some of the global emission scenarios described in IPCC SRES scenario (IPCC, 2000). The available output data from a number of AOGCMs for selected scenarios (A2, A1B, B1, B2) was downloaded from the IPCC-DDC website and, after regridding to a common 1° x 1° latitude–longitude grid, it was used (i) to validate the models over the South Asia region by comparing the simulated data for the base period (1961-1990) with the observed CRU data (New et al., 1999) and to determine the model biases, if any, and (ii) to develop coarse resolution climate change projections for the regions of interest based on an ensemble of GCM outputs for each scenario. The domain for the South Asia region covered by Pakistan extended from 5°N to 45°N and from 55°E to 95°E and that used by Nepal extended from 5°N to 33°N and from 65°E to 97°E. All the AOGCM datasets used in these analyses included monthly mean surface air temperatures and precipitation, which were available in most cases for the entire period beginning with 1961 and ending in 2099.

In order to evaluate the performance of different GCMs, the GCM simulated climatology (i.e. the spatial patterns of precipitation and temperature on annual and seasonal basis) over South Asia was compared with the observational data of two variables: precipitation and temperature, available in the form of CRU data set through the IPCC-DDC. All the GCMs were validated in this manner and the corresponding model biases for temperature and precipitation over Pakistan, Nepal and Bangladesh were obtained.

The projected changes of surface air temperature and precipitation were worked out for three time slices: 2010–2039 (2020s), 2040–2069 (2050s), and 2070–2099 (2080s) relative to the average values of those parameters during the 30 years baseline period 1961–1990. (For more information, please see Draft Reports DR-2, DR-3 and NDR-2 listed in Appendix IV and provided in the CD.)

2.3.1.3. RCM Based Climate Change Scenario Formulation

For the development of RCM based climate change scenarios for the South Asia region, two models: RegCM3 (Giorgi et al., 1999) and PRECIS (Jones et al., 2004) were used. Pakistan conducted experiments with both the models, while Nepal and Bangladesh used only RegCM3. The domain for the South Asia region covered by Pakistan was essentially the same as that used in the GCM ensemble based analysis (i.e. from 5°N to 45°N and from 55°E to 95°E); the one used by Nepal extended from 5°S to 45°N and from 50°E to 110°E and that used by Bangladesh extended from 5°N to 35°N and from 65°E to 120°E. RegCM3 could be driven by the output data from ECHAM5 of MPI, Germany or FVGCM of NASA, USA and by the ERA40 data (Reanalysis data of the European Centre for Medium-Range Weather Forecasting, ECMWF); PRECIS could be driven by the output data from HadAM3P model (Gordon et al., 2000) which is a high resolution atmospheric part of the Hadley Centre's GCM, HadCM3, or by ECHAM4 and by the ERA40 data. The other inputs to the RCM were the Global Land Cover Characterisation (GLCC) data at a resolution of 10 min, GTOPO30 global Topography data with horizontal grid spacing of 30-arc seconds (0.008 degree) and the Globally Interpolated Sea Surface Temperature (GISST) data, all being available from the INTERNET at RegCM3 website. For these experiments, the models were run at a horizontal resolution of 50 km or 0.44°.

To validate a particular model combination of GCM and RCM, the model's downscaled data for the base period (1961-1990) was compared with the CRU data as well as with the downscaled ERA40 data. In some cases, the available station data was also used for model validation. The model simulations were also checked for their ability to reproduce some selected major extreme events.

Convective precipitation still remains one of the most important sources of error in climate models. So, where possible, care should be taken in selecting a convective scheme in model simulation. Three options are available in RegCM3 to represent cumulus convection: (1) the modified Anthes-Kuo scheme (Anthes, 1977); (2) the Grell scheme (Grell, 1993); and (3) the The Emanuel or the MIT Scheme (Emanuel, 1991, Emanuel et al., 1999). A series of experiments were conducted by the teams in Pakistan and Nepal to identify appropriate scheme over the South Asia region. After evaluating a series of simulations from different convective parameterization, the Nepal team chose the Emanuel/MIT scheme with some parameter optimization, while the team in Pakistan opted for the Grell scheme (Grell, 1993; Fritsch et al., 1980).

For developing future projections, the model runs were conducted for SRES A2 scenario for the 30 year baseline period (1961–1990) and for various 30 year time slabs in the future as described below:

PRECIS with HadAM3P:	2080s (in Pakistan only)
RegCM3 with FVGCM:	2080s (in Pakistan only)
RegCM3 with ECHAM5:	2050s (in Pakistan, Nepal), 2080s (Pakistan)

(2050s = 2040-2069; 2080s = 2070-2099)

(During the tenure of this project, the effort by the Bangladesh team remained limited to validation of PRECIS and RegCM3.)

The climate change projections at annual, seasonal or monthly level for a future period for the whole domain were obtained by comparing the model simulated data for that period with the corresponding model simulated data for the baseline period.
(For more information, please see Draft Reports DR-4, DR-5, DR-6, DR-7, DR-8 and NDR-5 listed in Appendix IV and provided in the CD.)

2.3.2. Climate Change Impacts on Agriculture

2.3.2.1. CERES Crop Simulation Models:

The impact of climate change on agricultural productivity in Pakistan, Nepal and Bangladesh was studied using DSSAT-based CERES family of crop simulation models for cereal crops. CERES models are dynamic and mechanistic crop growth models that have been extensively used for the assessment of impacts of climate change on agricultural crop production in different regions of the world (Rao and Sinha, 1994; Rosenzweig and Iglesias, 1994; Otavio et al., 1994). These models simulate the duration of vegetative and reproductive stages, accumulation and partitioning of biomass, and grain yield for a specific cultivar (Hoogenboom et al., 1994; Ritchie et al., 1994; Tsuji et al., 1998). The DSSAT based model set was acquired under the framework of this project from the University of Georgia, Griffin, GA, USA, following the organization of a 2-week South Asia Regional Training Workshop on Simulation Modelling in Thailand from 28 June to 9 July, 2004. The CERES models were calibrated and validated under local conditions before their use for impact studies.

2.3.2.2. Data Requirements of the models

The main data requirements for the CERES models are:

a) Field Experimental Data (Crop Management, X File), Crop Yield and yield components (A File), and Crop Growth (T File)
b) Crop Genetic Coefficients Data (Cultivar file, Ecotype file and Species file)
c) Soil Data
d) Weather data (Maximum temperature, Minimum temperature, Rainfall, Solar radiation

2.3.2.3. Model calibration and evaluation

Pakistan: The agronomic data on wheat and rice growth required for calibration and validation of the CERES Wheat and CERES Rice models was arranged from the University of Agriculture, Faisalabad after entering into a Memorandum of Understanding under the framework of the present APN CAPaBLE Project.

For wheat, three sites were selected to represent varied weather conditions of the Punjab province of Pakistan. These were: Faisalabad and Sheikhpura (semi-arid), and Bahawalpur (Arid). Field observations were taken on growth stages of plant; total above-ground biomass (hereafter referred to as tops weight); grain number; unit grain weight; grain yield; and leaf area index. Growth stages were recorded at seedling emergence, tillering, stem elongation, spike emergence, anthesis and physiological maturity, corresponding to Zadoks growth stages 10, 20, 30, 50, 60 and 90 respectively.

The calibration of CERES-Wheat model was done using a high yielding cultivar of wheat (*Triticum aestivum L*.), Inqalab-91, grown over > 80% of the wheat area in Pakistan during 1990s, under soil and climatic conditions of arid and semi-arid zones. It is still being grown on considerable area in the country.

For calibration, the experimental data from the first (21 November) and second (15 December) planting dates under the nitrogen application rate of 150 kg ha^{-1} for Faisalabad location was used. The remaining treatments for the Faisalabad site and the experiments for the other two sites were subsequently used for model evaluation. The Faisalabad location was selected for calibration because the field experiment was conducted at the University Farm and was in close proximity of the research investigators for detailed observations.

Despite limited availability of the detailed observed data sets and number of discrepancies in the accuracy of observed data sets, the model simulated crop growth and development response reasonably well. The sensitivity of the model towards different nitrogen regimes and planting dates was similar to the observed data set. The model was also able to capture the environmental variability between locations satisfactorily for Faisalabad and Sheikhupura locations. However, the results for Bahawalpur were poor, especially the simulation of LAI over time. There was also an issue with the accuracy of the observed data set.

The model was able to simulate fairly well the number of observed parameters upon which the model performance was tested (phenology, biomass accumulation, leaf area index, and grain yield). But the model response to high temperature upon the simulation of unit grain weight needs further consideration, as this can be a major limitation to yield in sub-tropical environments.

For rice, the field experimental data on the effect of plant density (symbolized as P) and nitrogen levels (N) on growth and development was acquired from the Department of Agronomy, University of Agriculture, Faisalabad, Pakistan, for the year 2000 and 2001.

Grain yield response of cultivar Basmati Super to planting densities at the treatments P2N3 (planting density of 2 seedlings/hill and nitrogen level of 150 kg/ha) and P3N3 (planting density of 3 seedlings/hill and nitrogen level of 150 kg/ha) was selected to calibrate the model as these were the recommended levels of planting densities and nitrogen levels for farmer’s practice. The rest of the treatments were subsequently used for model evaluation.

The rice yield, like wheat yield, was simulated using soil and daily weather data at Faisalabad. Simulation results were validated against the observed data for the treatments that were not used for calibration. The root mean square error (RMSE) and index of agreement (d-stat) were used for model validation.

A comparison was made between the CERES-Rice model's simulated data and he observed data on days to anthesis, days to physiological maturity, yield at maturity, unit weight at maturity, number at maturity, tops weight at maturity, by-product harvest and harvest index at maturity under P2N3 and P3N3 treatments (described earlier). There was almost a perfect agreement between the predicted and observed number of days to anthesis, but slightly lower grain and biomass yield and yield components than the observed value for all the planting densities. The grain weight, grain number, grain yield, final biomass, and harvest index of Basmati Super were predicted reasonably well in the present study by CERES-rice model, unlike the observations of Amien et al. 1996). Thus with the help of genetic coefficients derived for the rice variety 'Basmati Super', the model was able to predict phenology and grain yield with fairly good accuracy, showing the ability of the model to simulate the growth of the crop.

Nepal: In Nepal the stations that were selected for the study of CERES-based simulation model for Wheat, Rice and Maize were divided into three agro-ecological zones i.e., Terai, Hill, and Mountain. For Terai region there were 10 stations from east to west, while for the hilly region there were 16 stations and for the mountain region there were 4 stations. For rice only one station was selected from the mountain zone; for other regions the number of stations was the same as mentioned above.

The daily weather data (Temperature, Rain and Solar Radiation or Sunshine hour), the crop parameters - yield, anthesis and maturity, which are highly influenced by the climatic variability and soil type were used to study the impact.

The calibration and validation of the models was first done by employing the experiments at Agricultural Experimental Station, Khumaltar, Lalitpur and several experimental stations representing different agro-ecological zones. The calibration was done using the standard Coordinated Varietal Trials (CVT) conducted at different locations of the country for an average of three years. Validation was performed with other CVT and few Farmers Experimental results, which were not used in the calibration analysis. The DSSAT generated seasonal files of each crop from over 30 locations to derive the results. The seasonal results were drawn from the average of 15 to 30 years depending on the availability of weather data.

Bangladesh: Official linkages were established with Bangladesh Agricultural Research Council, the Department of Agronomy of Bangabhandhu Sheikh Mujibur Rahman Agricultural University, Ghazipur (BSMRAU) and Department of Soil, Water and Environment of Dhaka University for sharing of data and collaboration in research on implications of climate change on crop agriculture. Soil profiles of 25 selected soil series representing a total of 476 soil series for Bangladesh were collected and transformed by the Dhaka University group into ICASA format for use with the DSSAT based crop models. Daily time series data on Tmax, Tmin, rainfall and sunshine hours (i.e. solar radiation) were collected from Bangladesh Meteorological Department and plugged into climate datasets of the models. Generic coefficients of three most commonly grown cultivars of rice (BR11, Brri Dhan 28 and Brri Dhan 29) and two wheat cultivars (Kanchan and Akbar) were calculated and subjected to validation and calibration.

2.3.3. Climate Change Impacts on Water Resources

2.3.3.1 Application of Watershed Models

During the course of this project the following 6 watershed models were acquired, tested and applied to simulate the river inflows from different watersheds in Pakistan and Nepal: DHSVM, UBC, HEC-HMS, BTOPMC, HFAM, and WatBal. The salient features of these models and their inputs and outputs are listed below.

DHSVM (Distributed Hydrological Soil Vegetation Model) is a grid-based fully distributed model developed by the University of Washington, USA in the 1990s (Wigmosta et al., 1994). It can be integrated with standard GIS databases and mesoscale climate models for the simulation of hydrological processes in their true spatial and temporal context. The required attributes include topography, soil properties, vegetation types as well as the distribution of stream channels and logging roads. It provides a dynamic (one day or shorter time step) representation of the spatial distribution of soil moisture, snow cover, evapotranspiration, and runoff production. It consists of a two-layer canopy representation for evapotranspiration, a two-layer energy-balance model for snow accumulation and melt, a multi-layer unsaturated soil model, and a saturated subsurface flow model. Meteorological inputs are precipitation, temperature, wind, humidity and incoming short-wave and long-wave radiation. Digital elevation data are used to model topographic controls on incoming shortwave radiation, precipitation, and air temperature and down-slope water movement. Surface land cover and soil properties are assigned to each digital elevation model (DEM) grid cell or pixel.

UBC is a semi-distributed model that was developed by the University of British Columbia, Canada in the 1970s for mountainous watersheds (Quick and Pipes, 1977). It calculates the total contribution from glacier melt, snowmelt and rainfall runoff. The model structure is based on hydrological behaviour as a function of elevation in the watershed. The maximum and minimum temperatures and precipitation data are input to the model. Daily watershed streamflow is the main output along with information on snow pack water equivalent, snow covered area, current soil moisture status, and groundwater storage of the watershed. As the watershed is divided into area-elevation bands, the above information is also obtained for each band separately. Each elevation band has a separate variable description of the watershed, such as the forested fraction, impermeable fraction, glacierized area etc.

HEC-HMS (The Hydrologic Modeling System) was designed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) to simulate the precipitation-runoff processes of dendritic watershed systems. It is applicable in a wide range of geographic areas for solving the wide range of problems, including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program may be used directly or in conjunction with other software for studies of water availability, flow forecasting, flood damage reduction, floodplain regulation, and systems operation.

BTOPMC is a physically-based distributed hydrological model being developed by the University of Yamanashi, Japan (Beven and Kirkby, 1979). It has been successfully tested and validated for various small and large watersheds in South Asia and Southeast Asia e.g. the Fuji river basin of Japan; the Kankai, Bagmati, Sunkoshi and Narayani River basins of Nepal; the Yellow river basin of China; and the Mekong river basin of Thailand and Vietnam.

HFAM (Hydrocomp Forecast and Analysis Modeling), is a physically-based continuous deterministic hydrological model that was developed in 1990s (Marino et al., 1997) and is distributed by Hydrocomp Inc. It divides a watershed into hydrologically homogeneous land segments; each segment is simulated independently using local data applicable for the segment. The hydrologic processes simulated by the model include: snow accumulation, snowmelt, evapotranspiration, interception, surface flow, subsurface flow, interflow and deep groundwater flows.

WatBal (Water Balance Model), developed in 1990s (Yates, 1996) is a monthly lumped integral model which models the hydrologic system by solving a time dependent differential equation involving the maximum soil water holding capacity, relative soil moisture depth, precipitation, evapotranspiration and total runoff. The meteorological inputs to the model are the observed stream flows, precipitation and potential evapotranspiration at monthly time steps. The model can compute potential evaporation by using an empirical method if the potential evaporation data are not available.

Pakistan: The studies conducted in Pakistan were based on the use of DHSVM and UBC models, with the UBC model accounting for most of the work. These two models were applied to simulate the flows from different watersheds contributing to Indus River. The comparison of simulated discharge at the outlets of sub basins with the observed discharge data was used as a guide to adjust the parameters during calibration. The trial and error method was applied to achieve water balance and then match with the observed hydrographs at the basin outlets. Both the models were first calibrated and then validated with the aid of the observed hydrological discharge records for these basins. Data from 25 hydro-meteorological stations was used for calibration and validation purposes. The historical climate and river flow data was obtained from Water and Power Development Authority (WAPDA). After its calibration and validation for the Indus River Basin, the UBC model was used for making a preliminary assessment of the impact of a hypothetical scenario of deglaciation and temperature rise on the annual and intra-annual flows of the Indus River.

Nepal: DHSVM was attempted to simulate the flows from the Bagmati basin (2700 km^2) gauged at Karmaiya, Khokna draining the Kathmandu valley (585 km^2), and two other small basins but the results were not satisfactory. So furtherwork with this model was discontinued for the present.

Three other models, namely: WatBal, HFAM and BTOPMC were then applied to Narayani River Basin which originates in the dry region of Mustang in the west and the Tibetan area in the east draining mainly the middle part of Nepal. The flow is observed at hydrological gauging station at Narayanghat. The total drainage area of the basin is 32,100 km^2 out of which 6300 km^2 lies above 5000 m elevation covering snow and ice part of the basin. After showing satisfactory performance these models were calibrated and validated for Narayani River Basin based on the available long term flow records from 1962 to 2003 according to which the river at the gauging site has an average flow of 1560 m^3/s, with its maximum and minimum discharge being 12,700 m^3/s and 156 m^3/s respectively. The models were then used for making preliminary assessments of the impacts of some hypothetical scenarios of temperature rise and increased precipitation on the mean, maximum and minimum flows of the Narayani River.

2.3.3.2. Study of Glacier Retreats

The glaciers in the Karakoram play a key role in the water inflows in Indus and other rivers in Pakistan, yet there is considerable uncertainty about the temporal changes in the physical sizes of these glaciers. While over the last one hundred years the mountain glaciers are found to be retreating worldwide (Haeberli and Hoelzle, 2001), the glaciers in the Hindukush-Karakoram-Himalaya (HKH) region are reported to be receding faster than in any other part of the world (Rees & Collins, 2004). As a result, fears have been expressed that the flows of Indus River System may decrease up to 30-40% over the second half of the 21st century (World Bank Report, 2006). On the other hand, widespread expansion of large glaciers in the Central Karakoram has recently been reported by Hewitt (2005).

Since the glaciers in the Karakoram have not been studied in sufficient details, GCISC has initiated research to monitor the changes in these glaciers using the Remote Sensing and GIS techniques. To start with, ortho-rectified cloud free images of Biafo glacier taken in month of October in two different years by Landsat equipped with Thematic Mapper in 1992 and Enhanced Thematic Mapper in 2000 were used. The segment of Biafo glacier was extracted from these images and the glacier boundary was delineated by on screen digitization in GIS environment. Image processing techniques like ratios of TM3/TM5, TM4/TM5 and NDSI (Normalized Difference Snow Index) were applied for improving the accuracy of the demarcation. The above ratios were applied for snow cover part while for debris cover part, the classified NDSI image, high pass filters and different colour composites were used to delineate the boundary up to the glacier snout. Furthermore 3D visualization by combining Digital Elevation Model (DEM) and satellite images by overlapping the digitized boundaries of glacier was used for accuracy. (For more information, please see Draft Reports DR-12 listed in Appendix IV and provided in the CD.)

2.3.3.3. Statistical Downscaling of GCM based Climate Scenarios

Use of Watershed Simulation Models for climate change impact assessment studies in the high mountainous regions requires high resolution climate change scenarios which are some times not available from the dynamic downscaling of GCM data. In such cases Statistical Downscaling Technique offers a useful alternative. Accordingly, an effort was made to make use of this technique to develop scenarios for change in temperature and precipitation at station level using GCM based climate change projections to year 2099.

First, the methodology for interpolation of climate variables for point data to establish grid data (at 1 km resolution) was optimized using the Monthly Mean Temperature and Precipitation data (1961-2000) for 50 stations obtained from Pakistan Meteorological Department (PMD). After trying out some 20 different interpolation techniques, the Backward Elimination method was selected for the present study. Next, the Hadley Centre GCM data was statistically downscaled at the station level using the regression technique. The downscaled data was then interpolated for generating high resolution temperature and precipitation maps using the Backward Elimination method. Using these maps the projected values of temperature and precipitation in different parts of Pakistan were worked out. (For more information, please see Draft Reports DR-9 and DR-10 listed in Appendix IV and provided in the CD.)

3. RESULTS & DISCUSSION

Some salient results of the work done under this CRP are discussed below. More details may be found in the publications, conference contributions and draft technical reports listed in Appendices II, III and IV.

3.1. Climatology

3.1.1. Analysis of Historical Data

Pakistan: The trends of mean annual temperature and precipitation (1951-2000) in various climatic zones of the country are shown in Figures 3 and 4, while the corresponding trend values on annual as well as seasonal basis are listed in Tables 1 and 2.

From Figure 3 and Table 1 (for temperature trends) it is noted that (i) the mean annual temperature has been increasing in most parts of Pakistan; only the Sub-Montane and Western Highlands and Lower Indus Plains show a decreasing trend, (ii) all the zones show an increasing trend for the pre-monsoon summer months (Apr-May), (iii) all the zones, except Zone V (Balochistan Plateau, which is an arid and hyper-arid region), show a decreasing trend for the monsoon period, (iv) the Greater Himalayan region shows an increasing trend throughout from December to May, and (v) Balochistan Plateau (Zones V) is getting warmer in all the seasons.

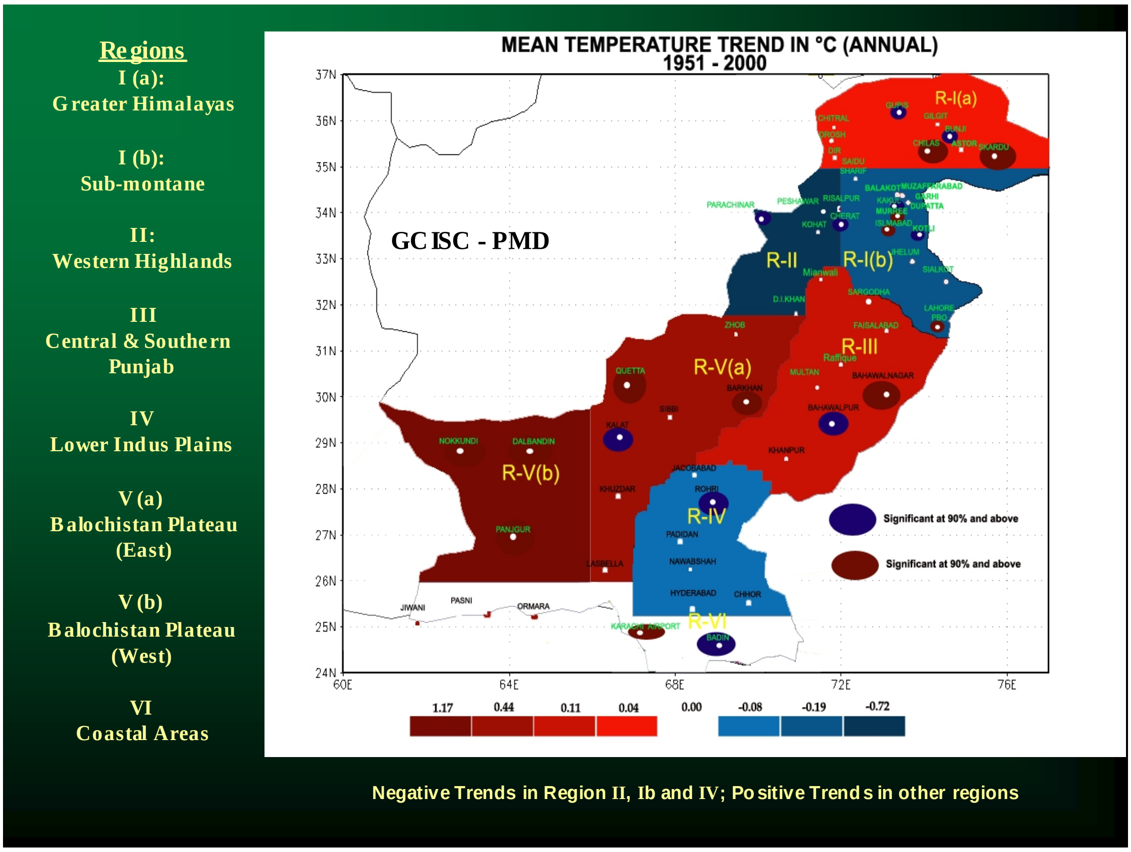

Figure 3: Mean temperature trends in °C (Annual), 1951-2000, Pakistan

Regarding precipitation, Figure 4 and Table 2 show that (i) the mean annual precipitation has generally been increasing except in Coastal Areas, (ii) the monsoon precipitation also shows essentially the same trend, (iii) the winter rains

Table 1: Mean Temperatures Trends in °C, 1951-2000, Pakistan

Regions/Seasons	Annual	Monsoon (Jun-Sep)	Winter (Dec-Mar)	Apr-May	Oct-Nov
I (a): Greater Himalayas	0.04	-0.80	0.32	1.09	-0.06
I (b): Sub-montane	-0.19	-0.57	0.00	0.13	0.12
II: Western Highlands	-0.72	-1.48	-0.65	0.17	-0.47
III: Central & Southern Punjab	0.11	-0.25	0.03	0.83	0.31
IV: Lower Indus Plains	-0.08	-0.55	-0.07	0.35	0.15
V (a) : Balochistan Plateau (East)	0.11	0.46	0.63	0.79	0.50
V (b): Balochistan Plateau (West)	1.17	1.3	0.43	2.17	1.80
VI: Coastal Areas	0.00	-0.18	0.05	0.03	0.30

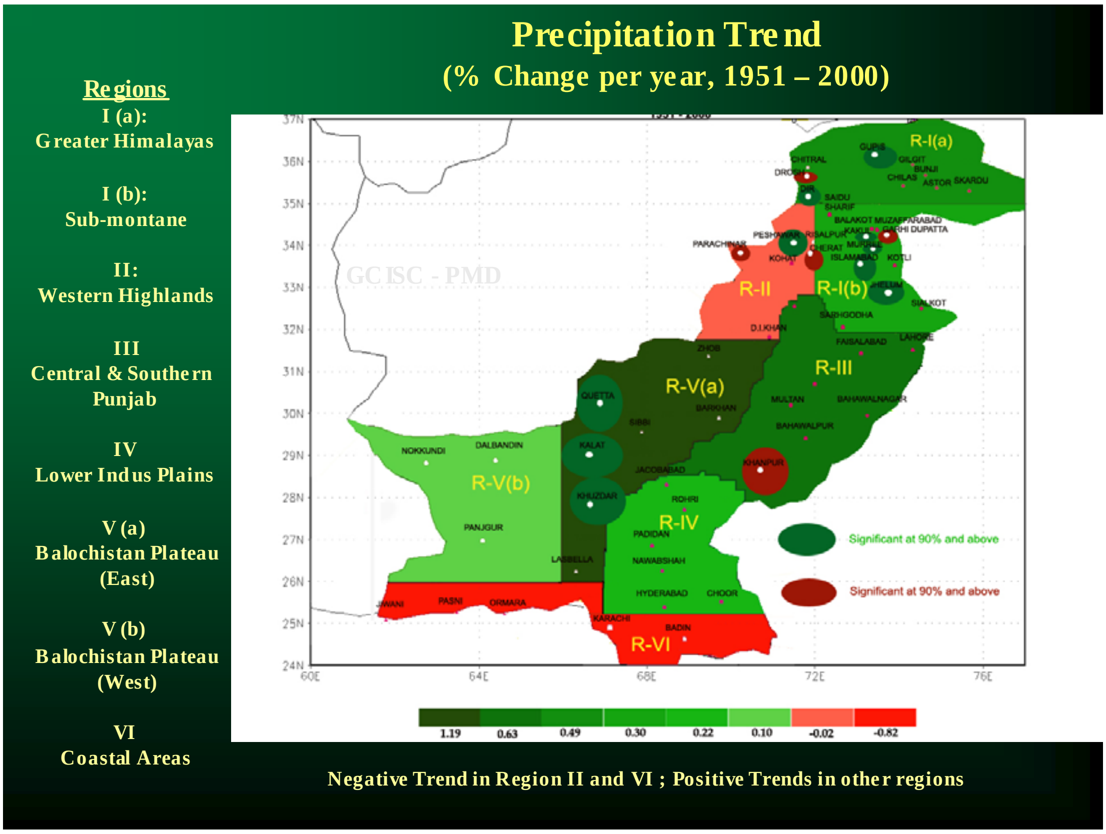

Figure 4: Precipitation trends (% change per year, 1951-2000), Pakistan

Table 2: Precipitation Trends, 1951-2000, Pakistan

Percentage Precipitation Changes (on yearly basis)

Regions/Seasons	Annual	Monsoon (Jun-Sep)	Winter (Dec-Mar)
I (a): Greater Himalayas	0.49	1.73	-0.04
I (b): Sub-montane	0.3	0.38	0.53
II: Western Highlands	-0.02	0.22	0.00
III: Central & Southern Punjab	0.63	0.57	0.99
IV: Lower Indus Plains	0.22	0.45	-0.27
V (a): Balochistan Plateau (East)	1.19	1.16	1.14
V (b): Balochistan Plateau (west)	0.1	-0.2	-0.4
VI: Coastal Areas	-0.82	-1.34	0.00

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show a mixed pattern with decreasing trend appearing in Western Highlands and a part of Balochistan Province (Sulaiman & Kirthar Ranges), and (iv) the Greater Himalayas show a trend of increasing precipitation during Monsoon period (June-September) and that of slightly decreasing precipitation in Winter months (December-March) monsoon precipitation.

(For more information, please see Draft Reports DR-1 listed in Appendix IV and provided in the CD.)

Nepal: In Nepal, study based on the data from 1975 to 2005 shows that the mean temperature of the country is increasing steadily at the linear rate of 0.04°C/year (Figure 5). This rate is much higher than the mean global rate. The mean annual temperature has increased by 1.7°C between 1975 and 2005.

The mean annual temperature is in general rising trend in almost the entire country except a slight decreasing trend in isolated patches in the northeastern region and the southern plains bordering mid and far-western region (Figure 6). By and large, the rate of increase of temperature is less in the lower altitude and high in the high altitude.

Monsoon rainfall occurring during June-September period constitutes more than 80% of the total rainfall in Nepal which varies from about 150 mm to over 5000 mm per annum (Figure 7). The linear trend of monsoon rainfall from 1971 to 2005 shows slight positive tendency amounting to about 2.08 mm/year underlying a very large inter-annual variation (Figure 8).

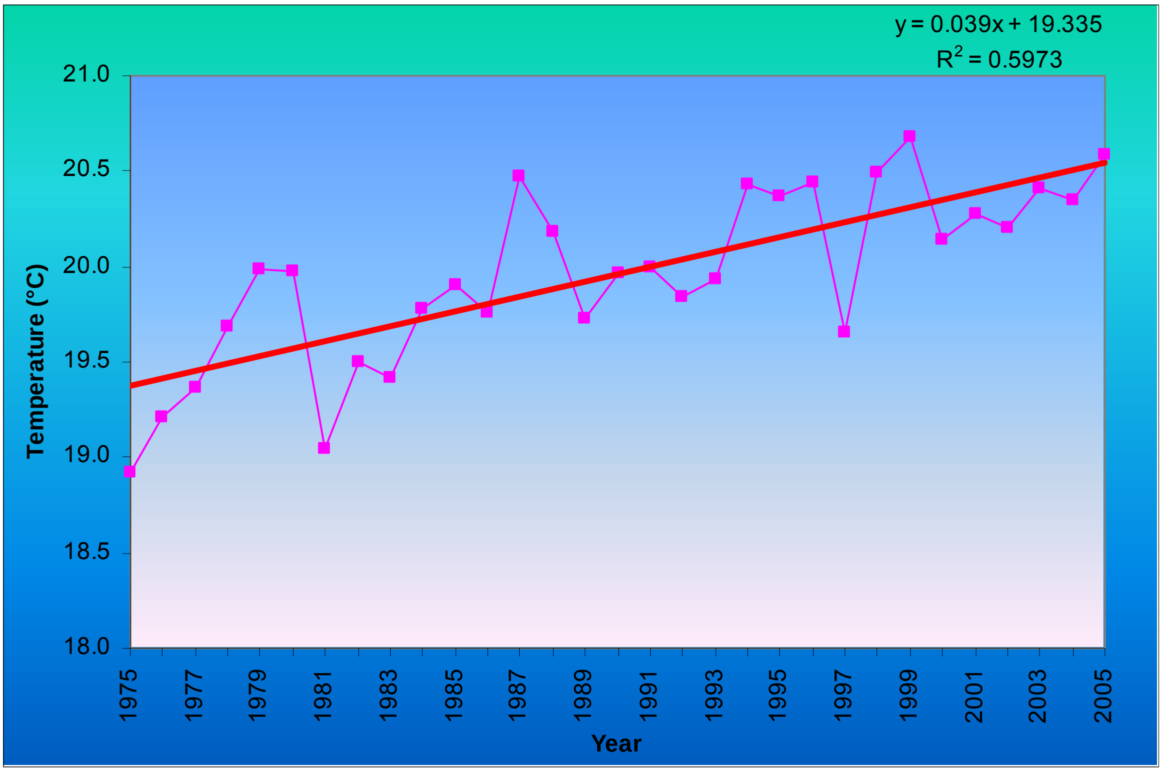


Figure 5: Annual mean all Nepal temperature trend

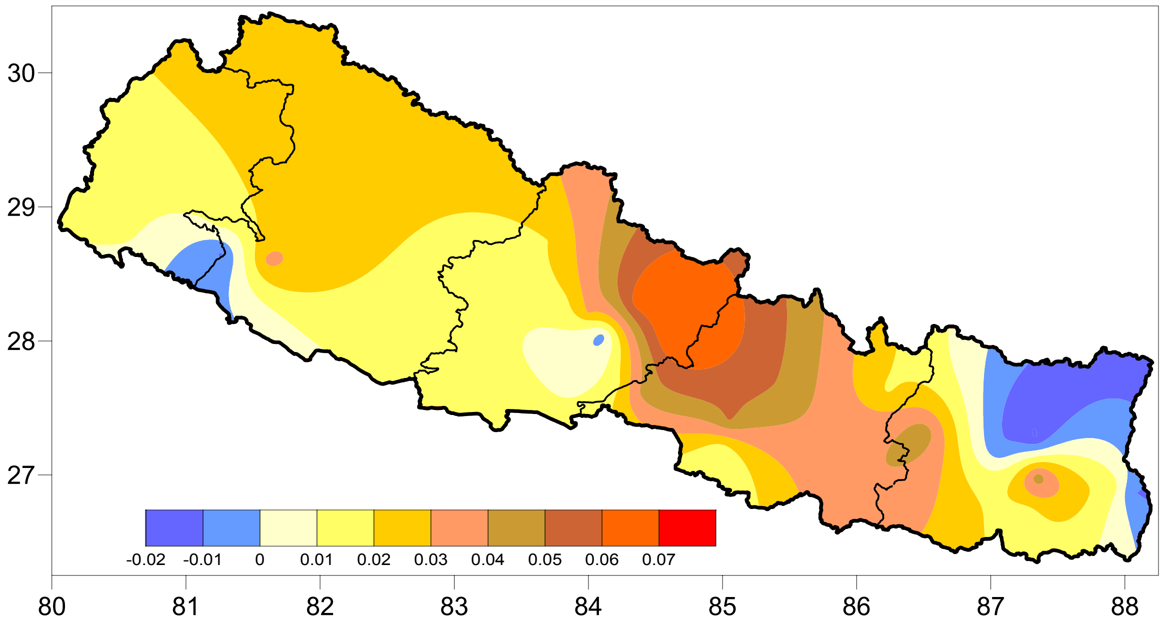


Figure 6: Annual mean temperature trend (°C/year), Nepal

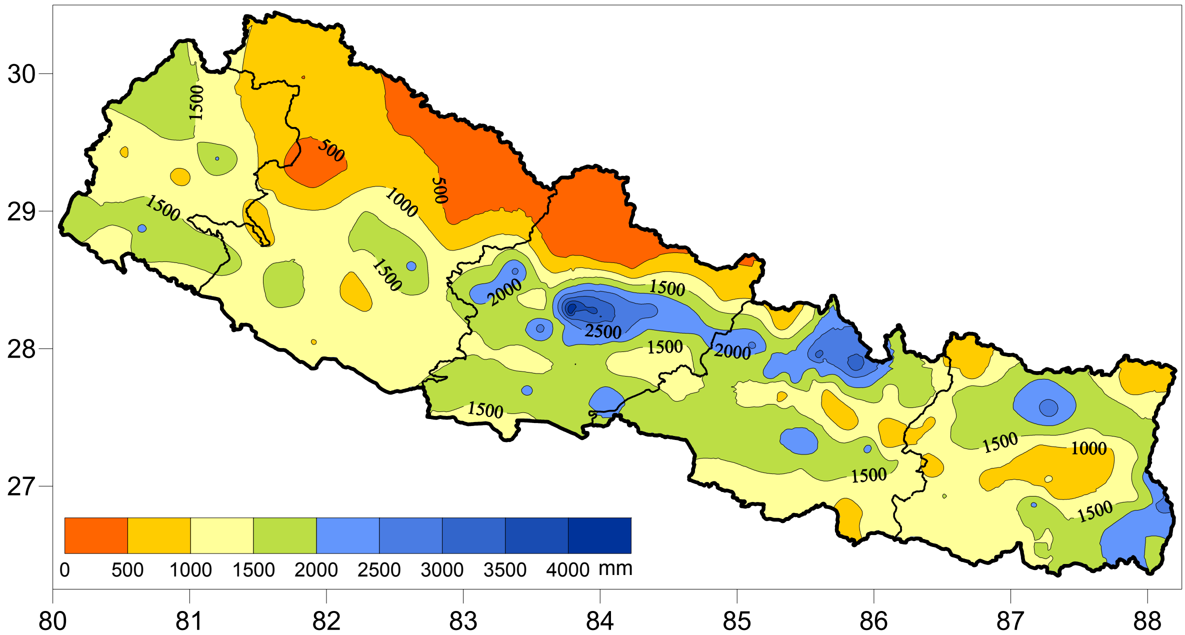


Figure 7: Spatial distribution of monsoon rainfall, Nepal

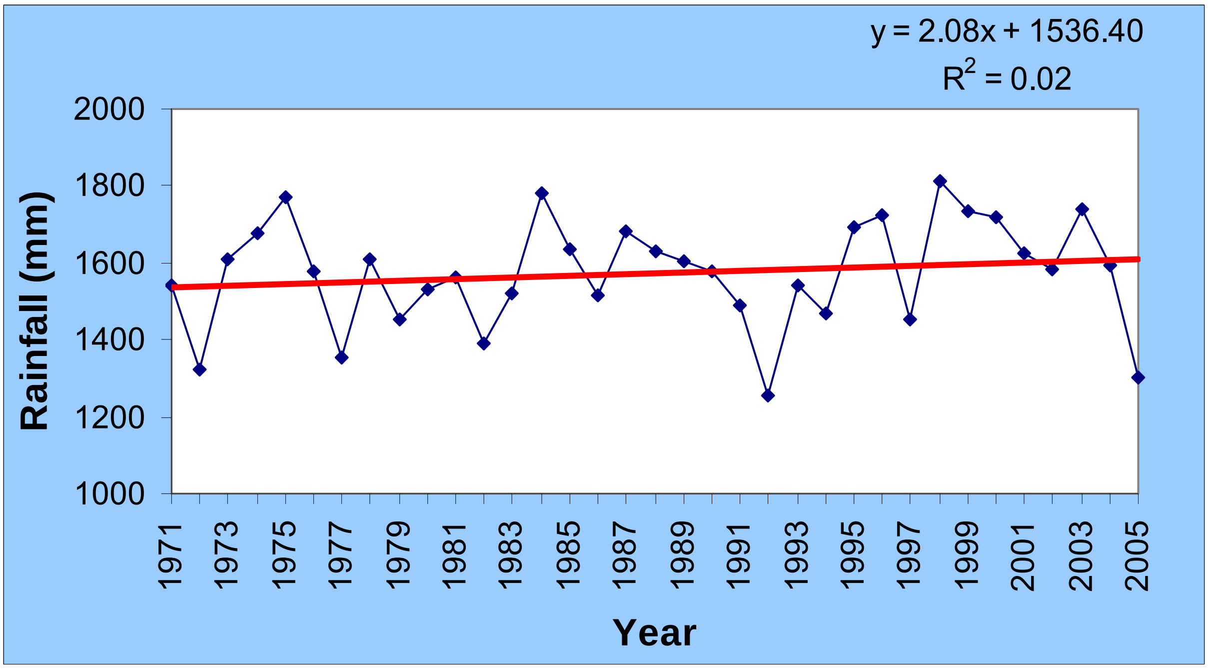


Figure 8: Nepal monsoon rainfall trend

(For more information, please see Draft Report NDR-4 listed in Appendix IV and provided in the CD.)

Bangladesh: In order to establish the past climatic trends, the following data sets of climatological parameters covering at least 24 stations spread over 6 divisions were assembled and analysed:

- Month-wise daily averages of Tmax, Tmin, and Tmean;
- Total rainfall per month per year;
- Seasonal average for Tmax, Tmin, and Tmean for the periods of peak monsoon (June

to August, JJA), monsoon (June to September, JJAS) and winter (December to February of the following year, DJF);

- Total monsoon (June to 10th of October, JJASO), winter (December to February of the following year, DJF) and annual rainfall per year;
- Year-wise episodes of dry-spells of short (>= 10 days), medium (>= 15 days) and long (>= 20 days) durations (e.g. see Figure 9);
- Wet spells expressed in number of wet days per year where rainfall per day is (>=40 to <50) mm, (>=50 to <65) mm, (>=65 to <90) mm, (>=90 to <105) mm, (>=105 to <150) mm, and (>=150) mm;
- Year-wise episodes of 'extreme wet' days where rainfall in 5 consecutive days is (>=100 to <150) mm, (>=150 to <200) mm, (>=200 to <250) mm, (>=250 to <300) mm, (>=300 to <400) mm, (>=400 to <500) mm, and (>=500) mm;
- Year-wise episodes of 'moderate wet' days where rainfall in 7 consecutive days is (>=100 to <150) mm, (>=150 to <200) mm, (>=200 to <250) mm, (>=250 to <300) mm, (>=300 to <400) mm, (>=400 to <500) mm, and (>=500) mm; and
- Dry episodes without rainfall per 10 year: 'moderate dry spell' (i.e. no rainfall in consecutive >= 10 days) and 'extreme dry spells' (i.e. no rainfall in consecutive >= 20 days).

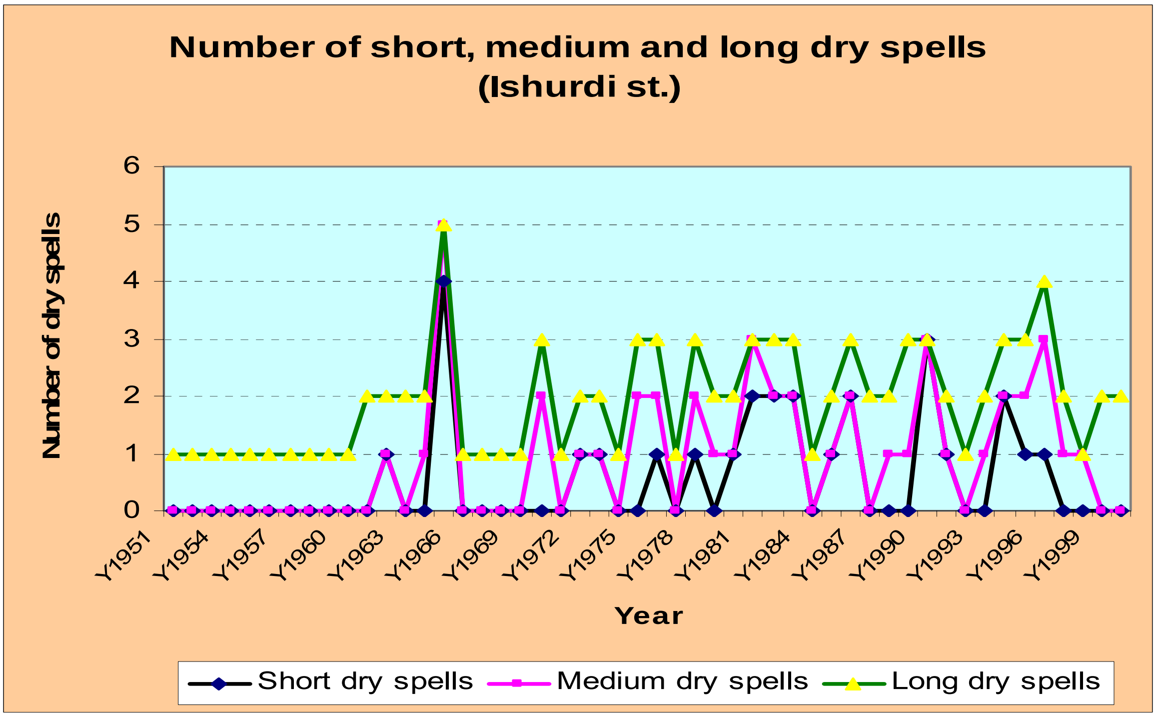


Figure 9: Year-wise episodes of dry spells recorded by Ishudri station, Bangladesh

A number of these data sets were subjected to decadal analysis (see e.g. Figure 10). Regression analysis was also done for the following sets of data for each station:

- Monsoon, winter and annual rainfall;
- Annual, winter and monsoon Tmax;
- Annual, winter and monsoon Tmin; and
- Annual, winter and monsoon Tmean (e.g. see Figure 11).

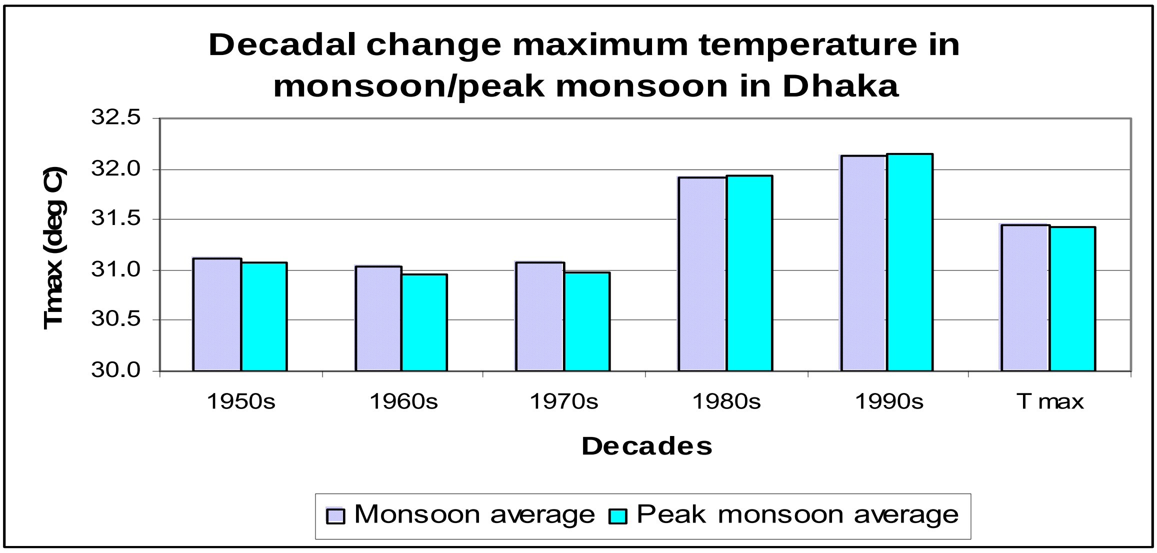


Figure 10: Decadal change in maximum temperature at Dhaka station (Bangladesh) during monsoon and peak monsoon periods, 1951-2000

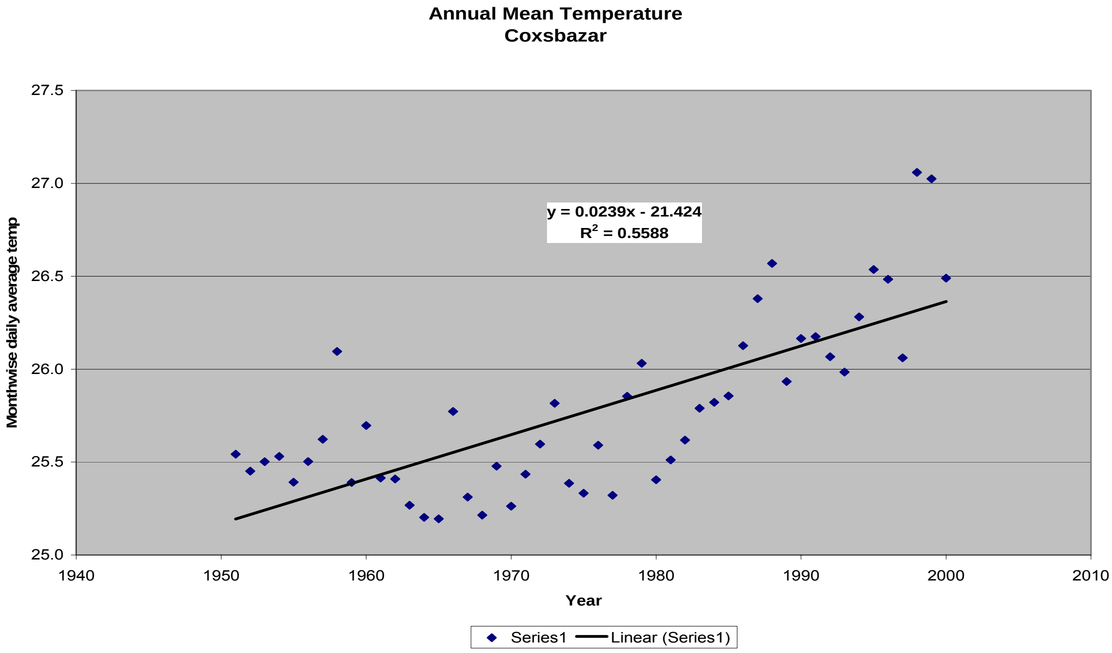


Figure 11: Regression analysis of mean annual temperature for Cox's Bazar Station, Bangladesh

3.1.2. Coarse Resolution GCM Ensemble Based Climate Change Scenarios

Pakistan: The group In Pakistan developed coarse resolution climate change scenarios for Pakistan Bangladesh and Nepal and for selected sub regions of Pakistan, corresponding to the SRES A2 and B2 scenario runs with 6 coupled AOGCMs used in the IPCC Third Assessment Report (TAR) (IPCC, 2001) as well as corresponding to the SRES A2 and A1B scenario runs respectively with 13 and 17 of the AOGCMs being used for the IPCC Fourth Assessment Report (AR4). Figure 12 shows the 13 GCM ensemble based projected changes in mean annual temperature (°C) and precipitation (in %) for 2020s (Future F1), 2050s (Future F2), and 2080s (Future F3), in scenario A2 over the South

Asia region (domain extending from 5°N to 45°N and from 55°E to 95°E). The gradual increase of temperature to varying extent in different parts of the South Asian domain as a function of time is quite obvious from the upper three figures of Figure 12. However, the patterns of temporal changes in precipitation in different parts of the domain (lower three figures of Figure 12) are rather complex.

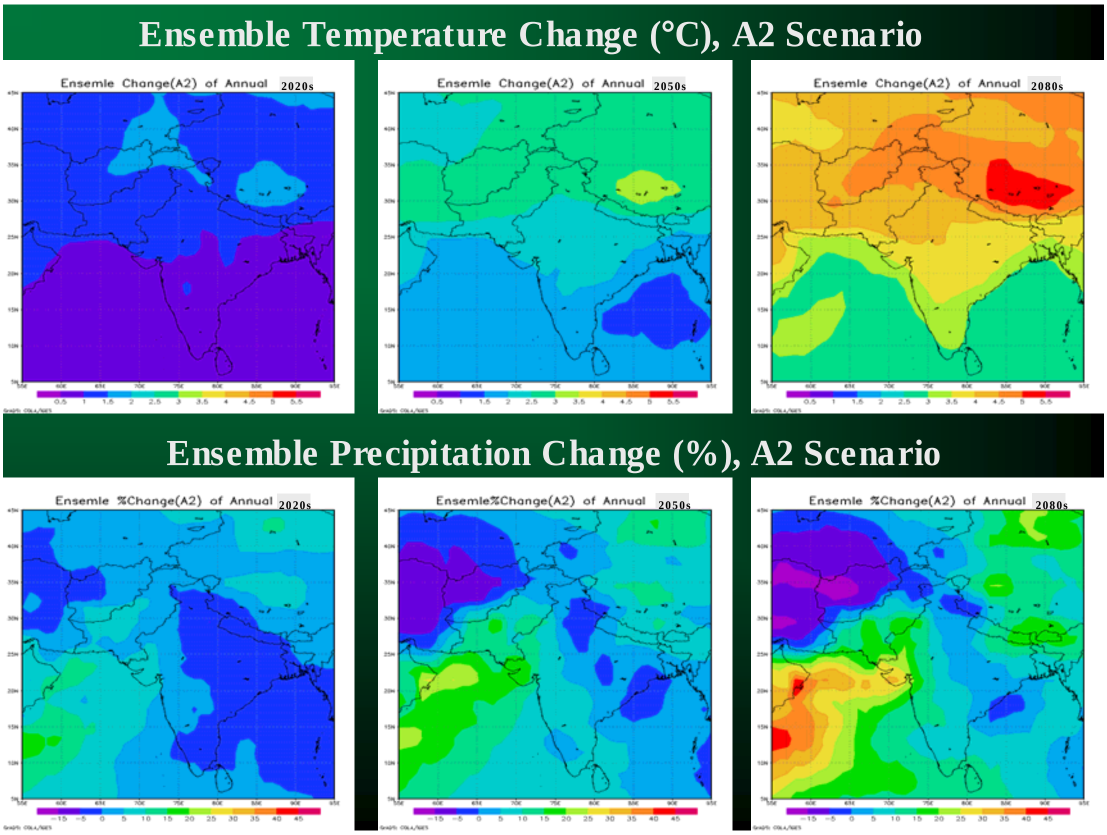


Figure 12: Mean 13 GCM ensemble based projected change of mean annual temperature (°C) (above) and mean annual precipitation (%) (below) over South Asia domain for 2020s (F1), 2050s (F2), and 2080s (F3) in A2 scenario

The area averaged values of GCM ensemble based projected changes in temperature on annual basis as well as for summer (JJAS) and winter (DJFM) over the regions (see Figure 13) covered by Pakistan, Nepal and Bangladesh are shown in Tables 3 and 4 for A2 and A1B scenarios respectively. The corresponding values for precipitation changes are provided in Tables 5 and 6. The errors shown here represent the standard deviations worked out on the basis of spread of the ensemble member values around the mean value. It may be noted that for all the three time horizons in both the scenarios, the rises in temperature on annual as well as seasonal basis in Pakistan and Nepal are comparable, while those in Bangladesh are relatively lower. Furthermore, there is a relatively larger temperature increase in winter than in summer in all the three countries. There are clear indications that in all the three countries, precipitation will increase in summer and decrease in winter (only a slight decrease in winter in Pakistan's case), while on annual basis it will increase in Bangladesh but have no significant change (within the large errors) in Nepal and Pakistan.

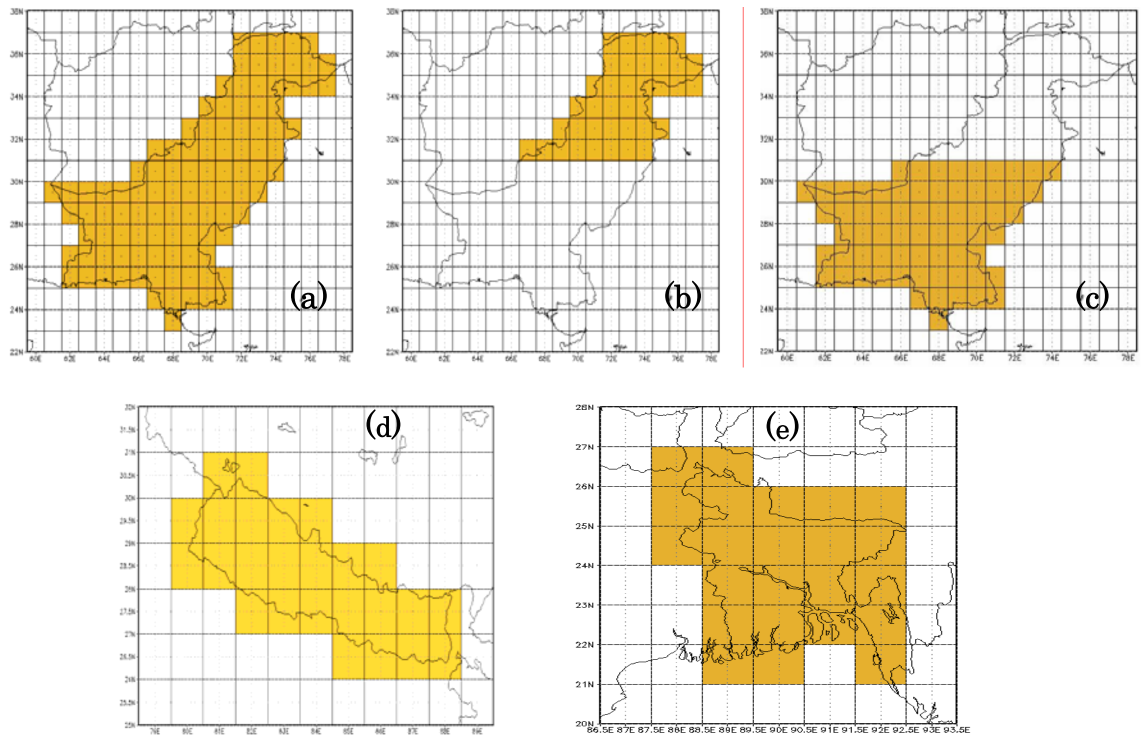


Figure 13: Grids covered in obtaining area averaged projections over (a) Pakistan, (b) Northern Pakistan, (c) Southern Pakistan, (d) Nepal, and (e) Bangladesh

Table 3: Projected changes in annual and seasonal temperatures (°C), in 2020s, 2050s and 2080s over Pakistan, Nepal and Bangladesh for A2 Scenario, based on 13-GCM Ensemble

	Temperature Change (°C), A2 Scenario		
	Pakistan	**Nepal**	**Bangladesh**
2020s			
Annual	1.31 ± 0.19	1.24 ± 0.20	0.87 ± 0.17
Summer	1.18 ± 0.12	1.05 ± 0.11	0.88 ± 0.08
Winter	1.43 ± 0.09	1.49 ± 0.11	0.99 ± 0.12
2050s			
Annual	2.54 ± 0.31	2.47 ± 0.33	1.90 ± 0.27
Summer	2.37 ± 1.19	2.09 ± 0.18	1.74 ± 0.11
Winter	2.66 ± 0.15	2.89 ± 0.14	2.21 ± 0.16
2080s			
Annual	4.38 ± 0.44	4.29 ± 0.47	3.41 ± 0.38
Summer	4.13 ± 0.26	3.67 ± 0.24	3.01 ± 0.16
Winter	4.47 ± 0.20	4.96 ± 0.19	3.90 ± 0.20

Table 4: Projected changes in annual and seasonal temperatures (°C), in 2020s, 2050s and 2080s over Pakistan, Nepal and Bangladesh for A1B Scenario, based on 17-GCM Ensemble

	Temperature Change (°C), A1B Scenario		
	Pakistan	**Nepal**	**Bangladesh**
2020s			
Annual	1.45 ± 0.09	1.40 ± 0.08	0.97 ± 0.05
Summer	1.30 ± 0.12	1.15 ± 0.12	0.91 ± 0.07
Winter	1.61 ± 0.11	1.71 ± 0.10	1.16 ± 0.08
2050s			
Annual	2.75 ± 0.14	2.68 ± 0.15	2.04 ± 0.10
Summer	2.60 ± 0.17	2.30 ± 0.17	1.81 ± 0.10
Winter	2.89 ± 0.15	3.11 ± 0.15	2.37 ± 0.14
2080s			
Annual	3.87 ± 0.20	3.83 ± 0.22	3.00 ± 0.14
Summer	3.70 ± 0.23	3.31 ± 0.25	2.65 ± 0.15
Winter	3.92 ± 0.21	4.36 ± 0.22	3.39 ± 0.17

Table 5: Projected changes in annual and seasonal Precipitation (%) in 2020s, 2050s and 2080s over Pakistan, Nepal and Bangladesh for A2 Scenario, based on 13-GCM Ensemble

	Precipitation Change (%), A2 Scenario		
	Pakistan	**Nepal**	**Bangladesh**
2020s			
Annual	2.79 ± 2.94	-3.60 ± 3.08	-1.02 ± 1.09
Summer	5.31 ± 4.13	-0.76 ± 4.07	-0.31 ± 1.15
Winter	-16.2 ± 2.84	-11.74 ± 2.69	-11.32 ± 4.17
2050s			
Annual	5.53 ± 4.63	1.81 ± 4.76	2.72 ± 1.79
Summer	12.55 ± 7.13	5.88 ± 6.67	3.09 ± 1.63
Winter	-1.62 ± 3.56	-10.93 ± 3.63	-9.58 ± 8.05
2080s			
Annual	3.48 ± 5.78	6.22 ± 6.56	8.39 ± 2.15
Summer	12.16 ± 8.91	14.98 ± 9.74	10.02 ± 1.48
Winter	-5.12 ± 4.78	-17.58 ± 2.53	-11.55 ± 6.46

Table 6: Projected changes in annual and seasonal Precipitation (%) in 2020s, 2050s and 2080s over Pakistan, Nepal and Bangladesh for A1B Scenario, based on 17-GCM Ensemble

	Precipitation Change (%), A1B Scenario		
	Pakistan	**Nepal**	**Bangladesh**
2020s			
Annual	-1.29± 2.32	-1.18± 2.55	0.62 ± 1.04
Summer	0.75 ± 3.46	1.53 ± 3.61	1.38 ± 0.76
Winter	-5.74 ± 2.19	-14.77 ± 2.23	-12.09 ± 3.91
2050s			
Annual	-0.97± 3.05	3.48 ± 3.85	5.42 ± 1.41
Summer	4.66 ± 5.90	8.73 ± 5.92	5.49 ± 0.90
Winter	-6.19 ± 3.21	-15.43 ± 2.71	-8.84 ± 4.75
2080s			
Annual	-0.4 ± 4.36	3.69 ± 5.76	7.37 ± 1.86
Summer	3.89 ± 6.89	9.16 ± 7.26	8.64 ± 1.38
Winter	-6.32 ± 3.58	-15.61 ± 2.86	-10.64 ± 6.37

Tables 7 and 8 provide information on the projected changes in annual and seasonal temperature and precipitation over Pakistan and its Northern and Southern parts (separated at 31° N) in 2080s. From Table 7 it is noted that (i) the temperature increases in both summer and winter are higher in Northern Pakistan than in Southern Pakistan, and (ii) the temperature increases in Northern and Southern Pakistan are higher in winter than in summer. In the case of precipitation projections (Table 8), the rather large errors make it difficult to draw any definite conclusions about the changes in precipitation. There is, however, some indication of precipitation increase in summer and decrease in winter in Southern Pakistan.

Table 7: Projected Temperature Changes (°C) in 2080s over Pakistan and its Northern and Southern parts for A2 Scenario based on 13-GCM Ensemble

	Pakistan	**Northern Pakistan**	**Southern Pakistan**
Annual	4.38 ± 0.44	4.67 ± 0.23	4.22 ± 0.18
Summer	4.13 ± 0.26	4.56 ± 0.28	3.90 ± 0.26
Winter	4.47 ± 0.20	4.72 ± 0.24	4.33 ± 0.18

Table 8: Projected Precipitation Changes (%) in 2080s over Pakistan and its Northern and Southern parts for A2 Scenario based on 13-GCM Ensemble

	Pakistan	Northern Pakistan	Southern Pakistan
Annual	3.48 ± 5.78	1.13 ± 3.95	4.28 ± 9.46
Summer	12.16 ± 8.91	7.08 ± 8.35	51.07 ± 39.78
Winter	-5.12 ± 4.78	-2.24 ± 4.10	-20.51 ± 9.05

Figure 14 compares the GCM Ensemble based projected changes in temperature in 2020s, 2050s and 2080s over Northern and Southern Pakistan corresponding to A2 and A1B scenarios. In both the scenarios the temperature increase in Northern Pakistan is larger than that in Southern Pakistan throughout the time horizon. Furthermore, as expected, the temperature increase throughout the time horizon is higher in A2 scenario as compared to A1B scenario.

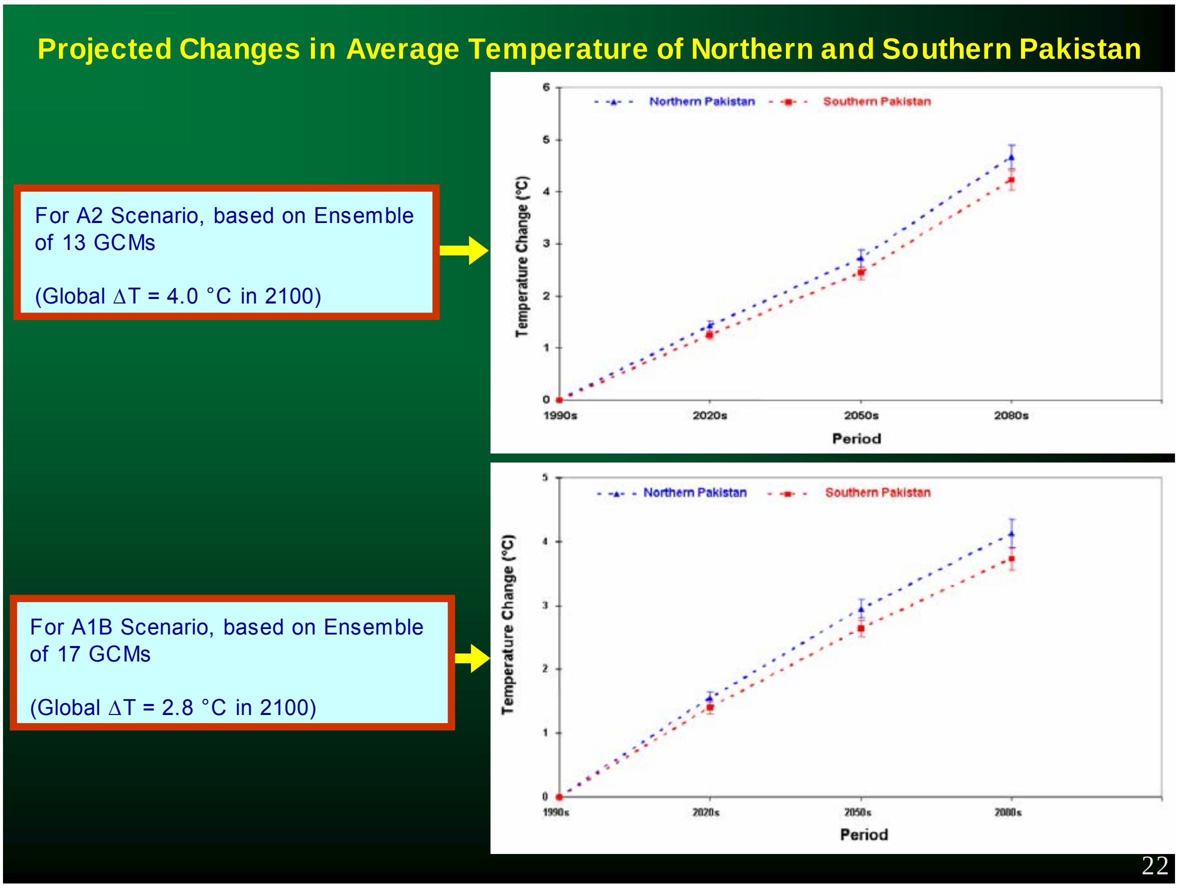


Figure 14: GCM Ensemble based projected temperature changes in 2020s, 2050s and 2080s over Northern and Southern Pakistan for A2 and A1B scenarios

Nepal: In Nepal similar analysis was carried out for the South Asia region (area extending from 5°-33°N and 65°-97°E) and for the Central Himalayan region covering Nepal and its vicinity (taken as an irregular box that extends from 78°- 89°E and 24°-32°N) (see Figure 15), using the outputs from an ensemble of 11 AOGCMs corresponding to SRES scenarios A2, A1B and B1.

Figure 16 shows model composite annual cycle of temperature and precipitation averaged over South Asia domain for the 30 year time slice each for reference period, 2020's, 2050's and 2080's for reference dataset, A2, A1B and B1 scenario. The Figure shows that seasonal cycle under different time periods and scenarios remains the same; however temperature is projected to increase throughout the year for all scenarios and time periods. Seasonal level analysis of these data shows that the increase in temperature is higher for winter months compared to summer months, which is consistent across the scenarios and time frame. In case of precipitation, it is projected to increase mainly during the summer months, especially monsoon, and decrease marginally during winter months.

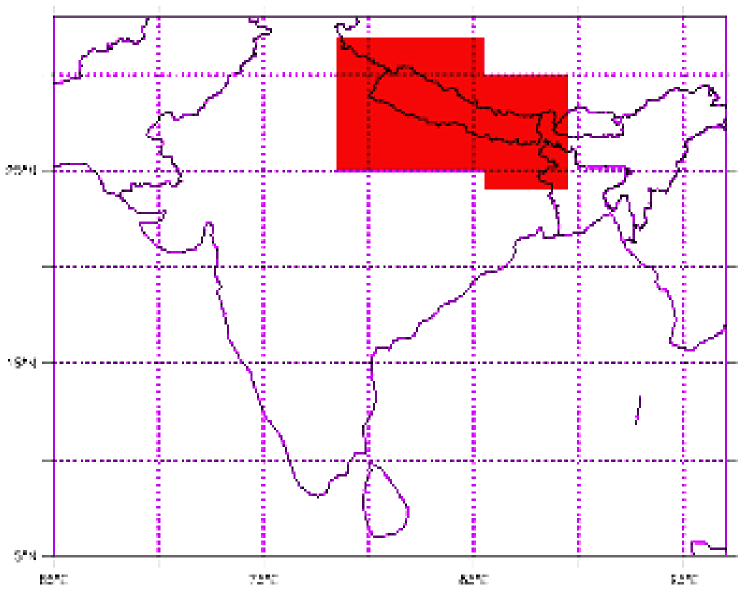


Figure 15: South Asia and Central Himalayan region (Nepal and vicinity) used in model validation and preliminary projections

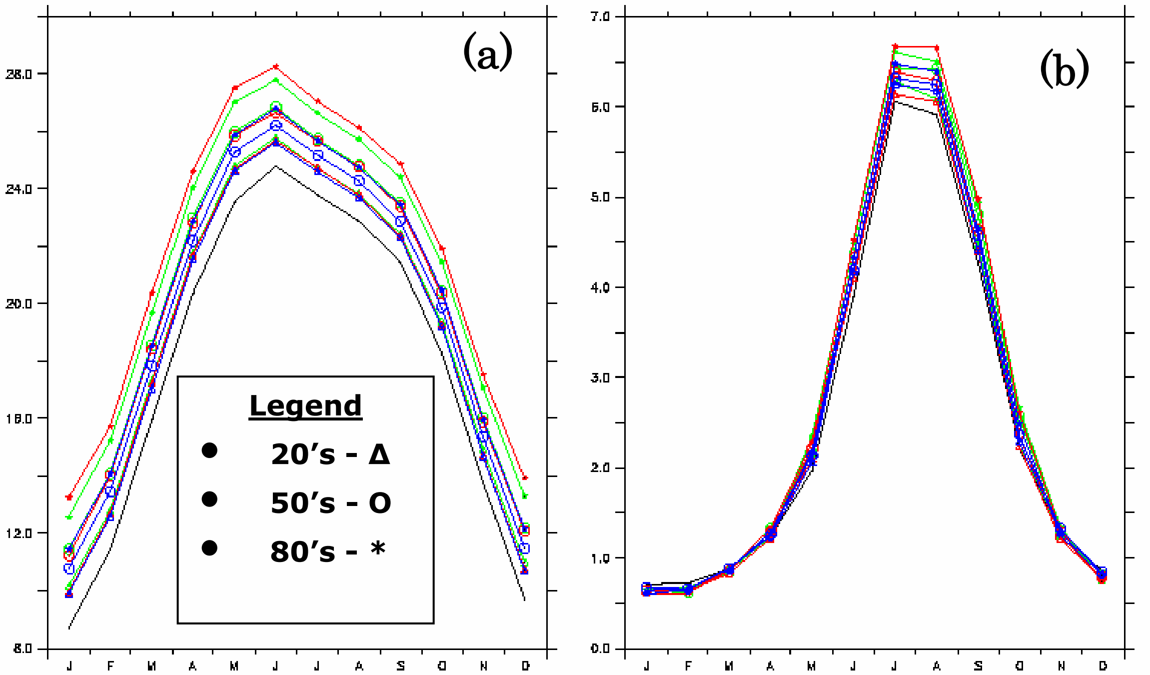


Figure 16: Ensemble mean Annual cycle of (a) Temperature (in °C) and (b) precipitation (in millimeter/day**)** over the South Asia domain. (A2 scenario is in red, A1B scenario in green, B1 scenario in blue and reference period in black)

Tables 9 and 10 respectively show the projected changes for temperature and precipitation under different scenarios averaged over South Asia and the Central Himalayan region. In the case of temperature the projected increase for the Central Himalayan region is slightly higher than the projected average increase over the South Asian region but in the case of precipitation the projected changes in the two regions are in line with each other.

Table 9: Projected changes in temperature and precipitation over South Asia

	Temperature Change (°C)			Precipitation Change (millimetre)		
Scenario	2020's	2050's	2080's	2020's	2050's	2080's
B1	1.0	1.7	2.3	28.5	45.8	61.5
A1B	1.2	2.4	3.4	29.4	73.0	94.3
A2	1.1	2.2	3.9	12.1	53.0	98.2

Table 10: Projected changes in temperature and precipitation over Central Himalayan region

	Temperature Change (°C)			Precipitation Change (millimetre)		
Scenario	2020's	2050's	2080's	2020's	2050's	2080's
B1	1.1	1.9	2.5	28.4	49.3	64.1
A1B	1.3	2.6	3.7	33.7	84.9	121.0
A2	1.2	2.4	4.2	1.6	58.4	124.6

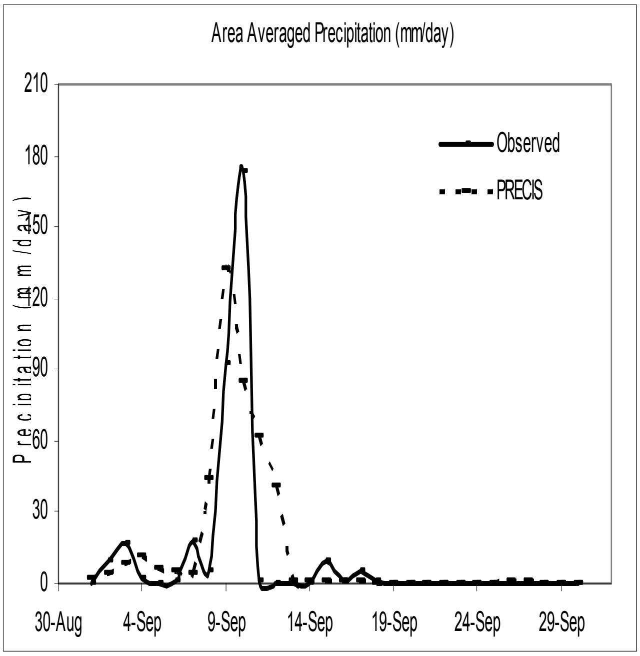
(For more information, please see Draft Reports DR-2, DR-3 and NDR-2 listed in Appendix IV and provided in the CD.)

3.1.3. Fine Resolution RCM Based Climate Change Scenarios

As mentioned in Section 2.3.1.3, two different RCMs were used for the development of fine resolution climate change scenarios: (1) PRECIS, which was used by Pakistan only, and (2) RegCM3, which was used by all the three countries: Bangladesh, Nepal and Pakistan. The results obtained are described below:

- **PRECIS**

Pakistan: Besides validating PRECIS over the South Asia domain against annual and seasonal base period values of temperature and precipitation, the model validation was also carried out for two synoptic weather events in South Asia, namely: a super cyclonic storm during 1999 in the Bay of Bengal and an extreme precipitation event of September 1992 in the Jhelum river catchment, both of which were quite nicely reproduced (see Figure 17 for the simulation of the September 1992 event).



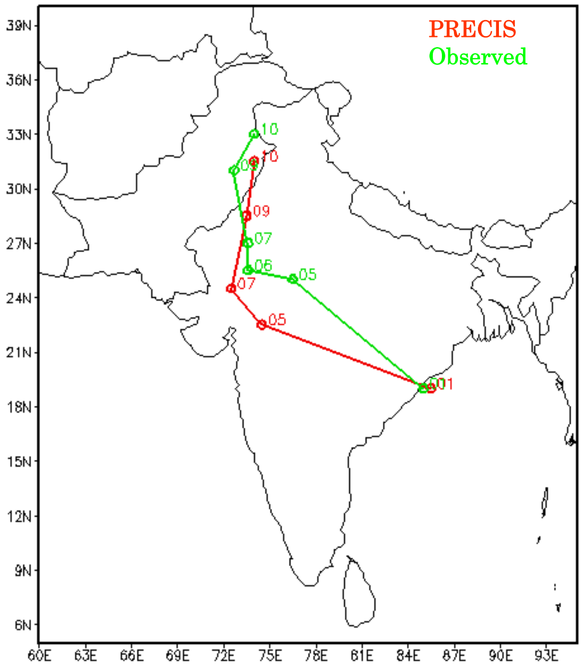


Figure17: (a) (Left figure) Area Averaged Daily Precipitation (mm/day) over the Jhelum River Basin during September 1992, and (b) (right figure) Simulated and Observed Tracks of Monsoon Depression

PRECIS driven by HadAMP3 was used to obtain fine resolution climate change responses for the South Asia region in 2080s under SRES A2 scenario. The simulated spatial patterns for the region (not reproduced here) show an increase of precipitation over the monsoon belt and over some central parts of India. There is an increase of winter precipitation over central India and northern parts of Pakistan, whereas in summer there is no significant change.

In Figure 18 the spatial patterns of changes in temperature and precipitation over Pakistan by 2080s are shown on annual and seasonal basis. The rise in annual mean temperature is 5.5°C over central Punjab, 3.5 to 4°C over costal areas and 4.5 to 5°C over the rest of the country. The rise of temperature in Pakistan in winter is generally more than that in summer. Over northern areas of Pakistan the increase in temperature is up to 6°C in summer whereas in winter the rise is in the range of 4 to 5°C. Winter precipitation has increased in the northern areas of Pakistan but the summer precipitation has decreased. The annual cycles of temperature and precipitation over Pakistan are shown in Figure 19. It may be noted that there is no net change in the average monthly precipitation over Pakistan as a whole.

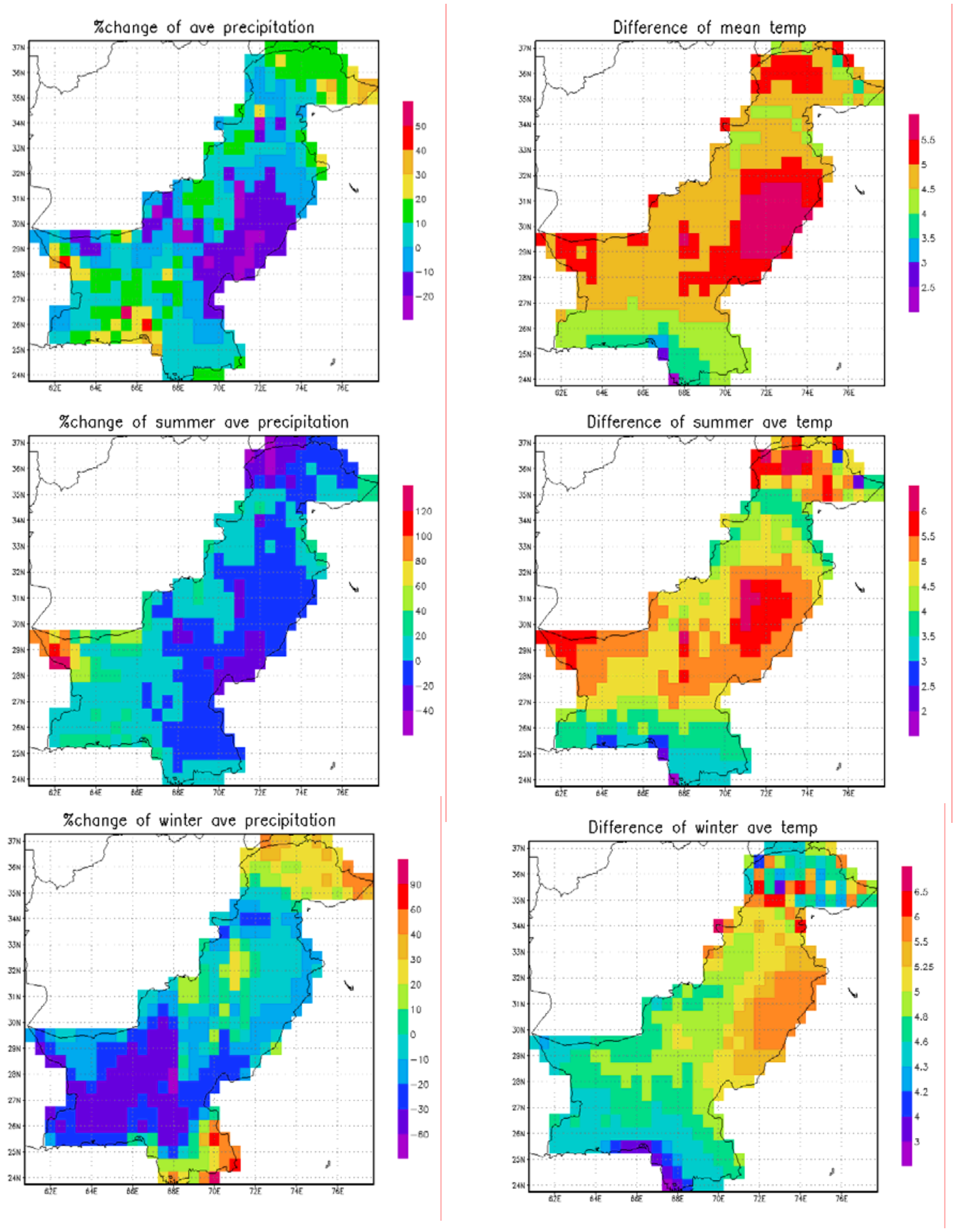


Figure 18: PRECIS based projected % changes in mean annual, summer and Winter precipitation of Pakistan region in 2080s in A2 scenario compared to (1961-1990) period (left column) and the corresponding changes in annual, summer and winter temperature

in °C (Right column)

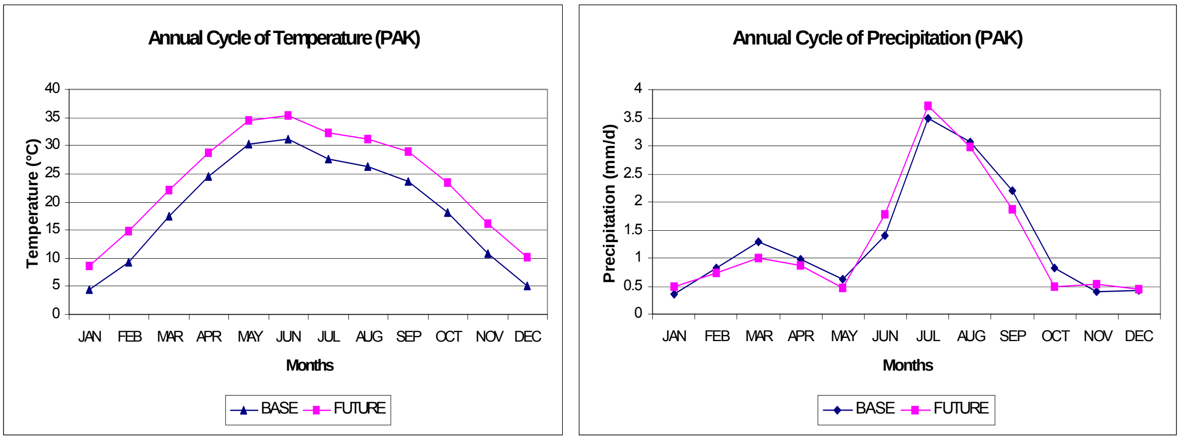


Figure 19: Month-wise Variation of Temperature and Precipitation in Pakistan in 2080s compared to 1990s, as per PRECIS Results for A2 Scenario

Figures 20 and 21 show changes in temperature and precipitation for Bangladesh in 2080s. Most of the central and western parts of Bangladesh have temperature change in the range of 4 to 4.5°C, while the coastal regions in the south and southeast have temperature change ranging from 2.5 to 4 °C. Precipitation in the eastern half of the country has increased in the range of 40 to 70 %, while the western half of the country shows an increase of 15 to 40 %.

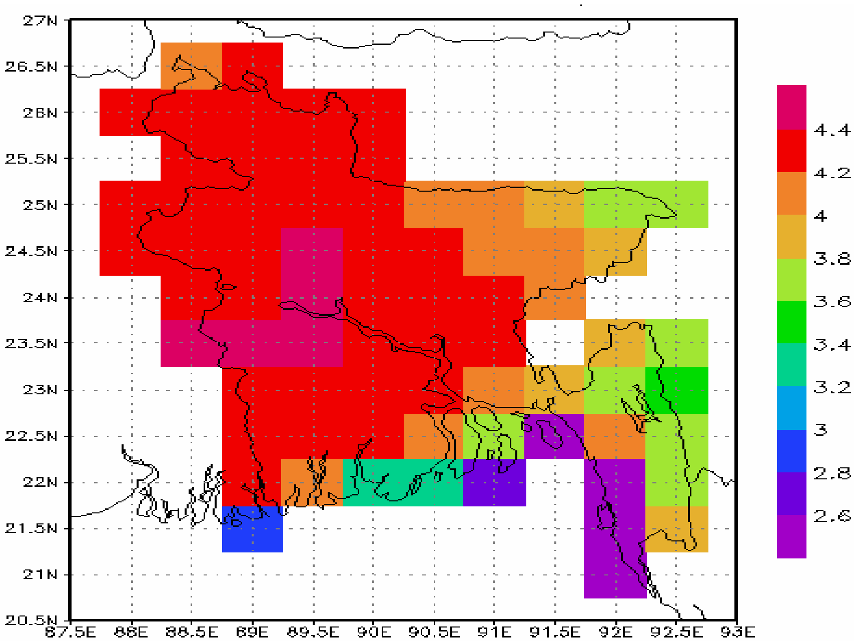


Figure 20: Projected Temperature Change (°C) over Bangladesh for 2080s by PRECIS for A2 Scenario

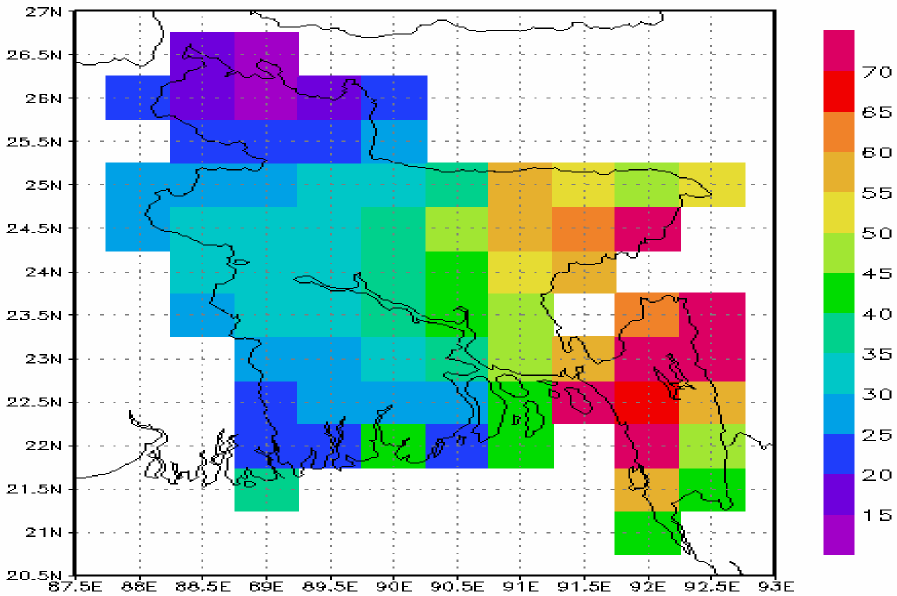


Figure 21: Projected Annual Precipitation Change (%) over Bangladesh for 2080s by PRECIS for A2 Scenario

The temperature and precipitation changes for Nepal in 2080s are shown in Figures 22 and 23. The northern parts of the country show higher increases in temperature than the middle and southern parts. The middle part of the country has the lowest temperature increase. Precipitation changes are higher in the eastern and southern parts of Nepal as compared to the northern parts. (For more information, please see Draft Reports DR-4, DR-5 and DR-6 listed in Appendix IV and provided in the CD.)

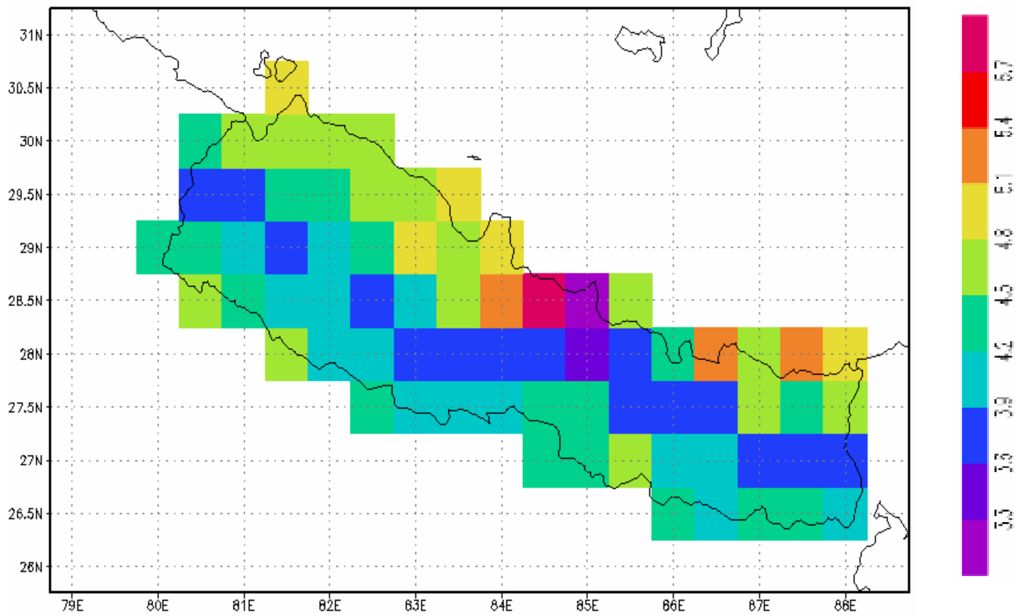


Figure 22: Projected Temperature Change (°C) over Nepal for 2080s by PRECIS for A2 Scenario

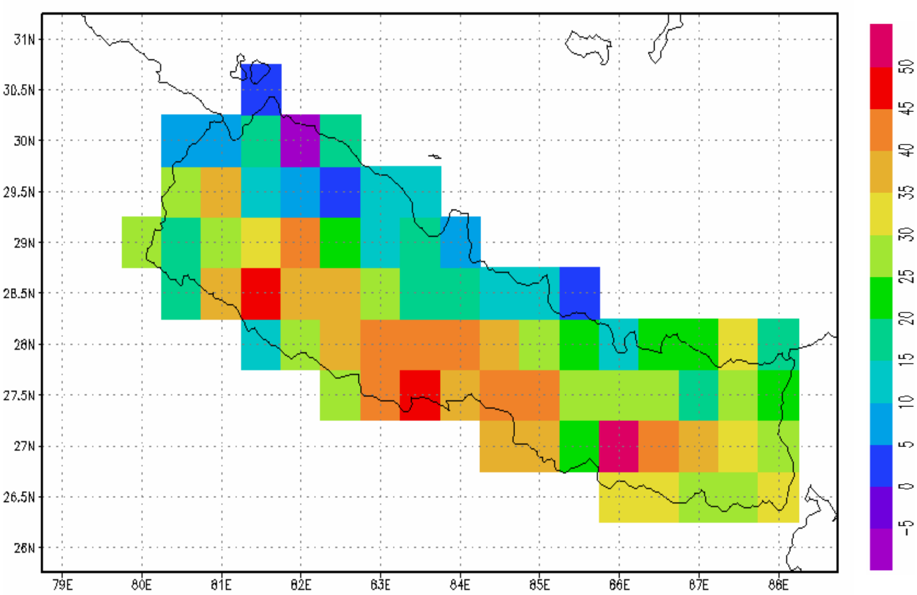


Figure 23: Projected Annual Precipitation Change (%) over Nepal for 2080s by PRECIS for A2 Scenario

Bangladesh: PRECIS has been validated against the recent climatology of Bangladesh, in particular by comparing its output against the surface rainfall collected at 118 locations throughout Bangladesh from 1980 to 1990. With ERA15 as the input, the model can calculate about 86% of the surface rainfall. PRECIS overestimates rainfall during dry and pre-monsoon seasons but underestimates it during monsoon season.

- **RegCM3**

*(**NOTE:** At three different occasions during the course of this work, some bugs were discovered in the model software by the developers of the RegCM3 model, necessitating each time to restart the simulation runs after removing the bug. As a typical RegCM3 simulation experiment for the South Asia domain covering a 30 year horizon conducted on a Pentium-4 PC takes about 3-4 months of continuous computer operation, it takes 6-8 months to complete the simulation for one particular 30-year time slab in the future along with the simulation of the 30-year base period (1961-1990), and the time requirement increases to 9-12 months if two 30-year time slabs in the future are to be covered. Accordingly, the interruptions caused by the discoveries of bugs in the model software did not allow sufficient time to complete the envisaged simulation experiments based on the final version of RegCM3 within the time duration of this project. The results for climate change projections briefly presented below are based on the work done before the final version of RegCM3 was put to use and should therefore be considered as tentative only. More detailed information on the RegCM3 based results and the problems caused by the bugs is provided in the Reports DR-8 and NDR-5 listed in Appendix IV and provided in the CD.)*

Pakistan: To test the performance of the model, a number of simulations were carried out using the ERA40 as driving data set while for comparison, CRU data set was used. The model was validated for two seasons i.e. winter (DJFM) and summer (JJAS) for two dry (1987 and 1985) and two wet (1991 and 1992) years as well as for some past extreme climate events. For seasonal validation, sixteen experiments were conducted while for the extreme climate events, simulations included flood event of August 1997 in the Jhelum catchment, the extreme precipitation event of 23rd July 2001 in Islamabad and the Tropical Cyclone of May 1985 in the Bay of Bengal. The overall model performance, including its ability to capture local events like monsoon and extreme precipitation and to simulate the path of tropical cyclone and wind patterns, was found to be quite satisfactory. (For more information, please see Draft Reports DR-7 listed in Appendix IV and provided in the CD.)

After validation the model was run with ERA40, ECHAM and FVGCM datasets at a horizontal resolution of 50 km to construct climate change scenarios for South Asia region under SRES A2 scenario. The results were analyzed on annual and seasonal basis. The projected changes in temperature and precipitation over Northern and Southern Pakistan are listed in Tables 11 and 12. Both the sets of results (one with ECHAM-RegCM3 combination and the other with FVGCM-RegCM3 combination) show greater warming in Northern Pakistan than in Southern Pakistan in summer as well as in winter and that the warming in summer will be slightly greater than that in winter. For the 2080s period (for which projections are available from both the model combinations), the ECHAM based projections for both parts of the country show greater warming than the FVGCM based projections. As for precipitation, both the model combinations show an increase in winter precipitation and a slight decrease in summer precipitation in Southern Pakistan; for Northern Pakistan there is no clear cut indication of precipitation change either in summer or in winter. (For more information, please see Draft Reports DR-8 listed in Appendix IV and provided in the CD.)

Table 11: Projected change in temperature using RegCM3, Pakistan

TEMPERATURE CHANGE (°C)			
(ECHAM, 2050s)			
	Annual	**Summer (JJAS)**	**Winter (DJFM)**
Northern Pakistan	2.53	2.97	2.01
Southern Pakistan	2.35	2.73	1.72
(ECHAM, 2080s)			
Northern Pakistan	5.09	5.56	4.55
Southern Pakistan	4.65	5.20	3.88
(FVGCM, 2080s)			
Northern Pakistan	4.09	4.46	3.77
Southern Pakistan	3.86	4.23	3.34

Table 12: Projected change in precipitation using RegCM3, Pakistan

PRECIPITATION CHANGE (%)			
(ECHAM, 2050s)			
	Annual	**Summer (JJAS)**	**Winter (DJFM)**
Northern Pakistan	2.69	-0.86	6.50
Southern Pakistan	2.04	-2.87	43.15
(ECHAM, 2080s)			
Northern Pakistan	5.38	2.42	-2.79
Southern Pakistan	-11.83	-27.68	34.50
(FVGCM, 2080s)			
Northern Pakistan	3.12	-7.72	1.94
Southern Pakistan	-1.38	-8.71	19.98

Nepal: After conducting a series of experiments to identify the most appropriate convective scheme over the South Asia region, the MIT Emanuel scheme with some parametric optimization and smoothing of the terrain was chosen for the scenario simulation. RegCM3 was then validated over Nepal for four seasons for the base line period (1961-1990) using the two major parameters: mean temperature and precipitation. The chosen seasons were: winter (December–February), pre-monsoon (March–May), monsoon (June–September) and post-monsoon (October– November). The model outputs were compared with Climate Research Unit (CRU) data as well as with the station data on precipitation, which is available in gridded form. Table 13 shows the area averaged temperature bias in the eastern and western Nepal (separated at 84.0° E longitude) in various seasons as well as on annual basis. The model produces cold bias ranging between -1.3°C to -3.3°C in both the regions in all seasons. The values of area averaged precipitation biases are shown in Table 14. In all the seasons the model over estimates precipitation but the wet bias with the CRU data is throughout higher than that with the station data, the difference being particularly large in the case of East Nepal.

RegCM3 driven by ECHAM5 GCM was run for SRES–A2 scenario over the South Asia domain at a horizontal resolution of 50 km. The model simulation runs were conducted over two periods of roughly 30 years: the base line period (1961-1990) and the mid-21st century period 2039–2069, with a few of months of extra time for the model spin up. Monthly averages of the output files were computed and climatological average were computed from those files. The changes in seasonal and annual climatology of Nepal and for its area averaged western and eastern parts in the mid-21st century period were studied compared to the corresponding base line situation.

Table 13: Bias in model mean temperature (°C), Nepal

	West Nepal	**East Nepal**
Winter	-2.4	-2.3
Pre-Monsoon	-1.3	-1.4
Monsoon	-1.8	-2.8
Post-monsoon	-2.5	-3.3
Annual	-1.9	-2.4

Table 14: Bias in Model Precipitation (%), Nepal

	West Nepal		**East Nepal**	
	Bias with Station data	**Bias with CRU data**	**Bias with Station data**	**Bias with CRU data**
Winter	158.3	166.8	64.4	237.9
Pre-Monsoon	155.8	166.4	59.9	207.2
Monsoon	21.5	51.2	24.2	55.3
Post-monsoon	366.8	359.1	61.2	188.6
Annual	60.1	90.4	37.0	87.6

The results for future projections (Figures 24-28) depict warming in all seasons in mid 21st century compared to base. The warming is higher in the northern part over high Himalayas than in the southern part. More over, the warming is highest in the winter season and minimum in the pre-monsoon season both in the west and east Nepal. Precipitation change analysis shows decrease in precipitation in the eastern Nepal in all the seasons and significant increase in southwestern and northwestern parts in the monsoon and pre-monsoon seasons. The annual cycle analysis shows the delay in precipitation peak in the western Nepal by a month (Figure 29). (For more information, please see Draft Reports NDR-5 listed in Appendix IV and provided in the CD.)

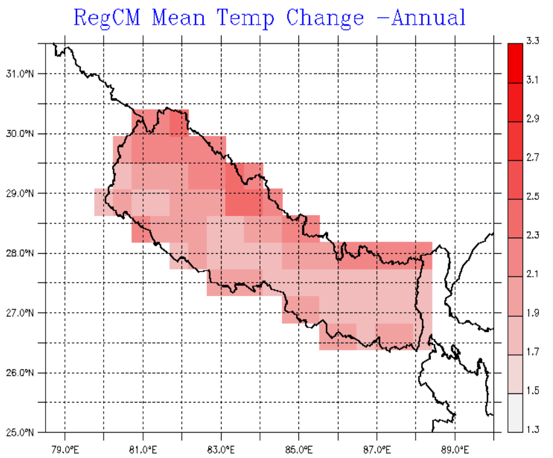


Figure 24a: Mean annual temperature change (°C), Nepal

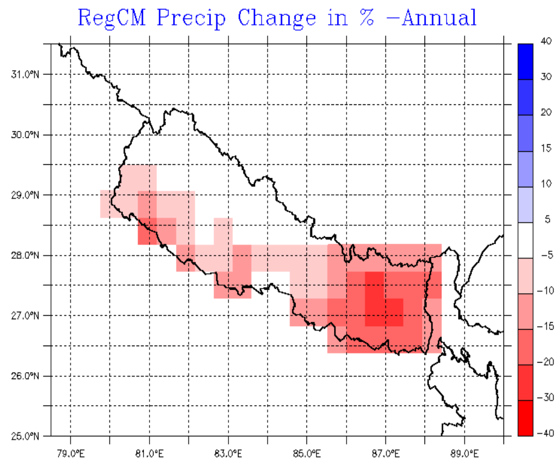


Figure 24b: Mean annual precipitation change (%), Nepal

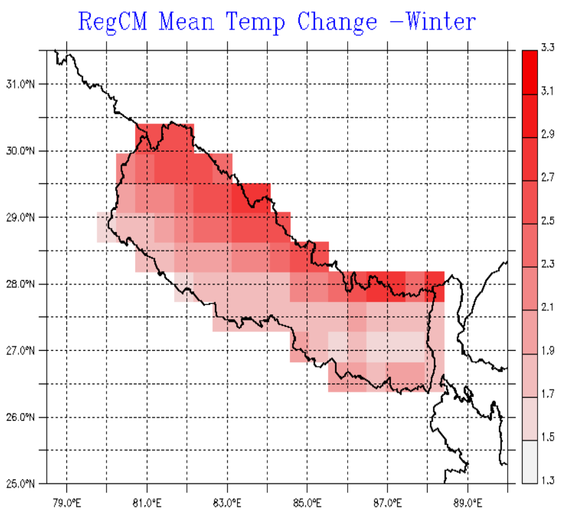


Figure 25a: Mean winter temperature change (°C), Nepal

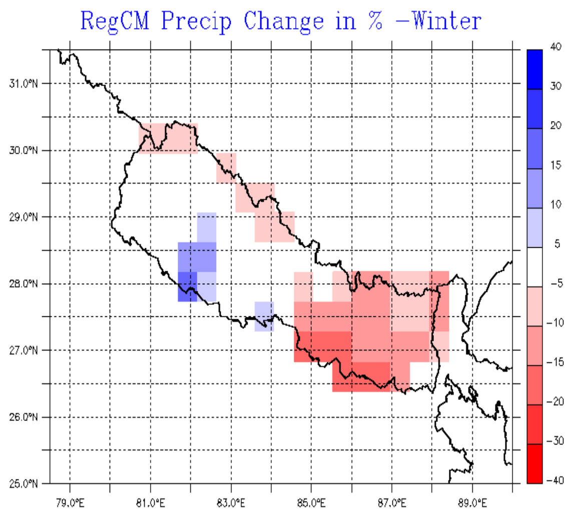


Figure 25b: Mean winter precipitation change (%), Nepal

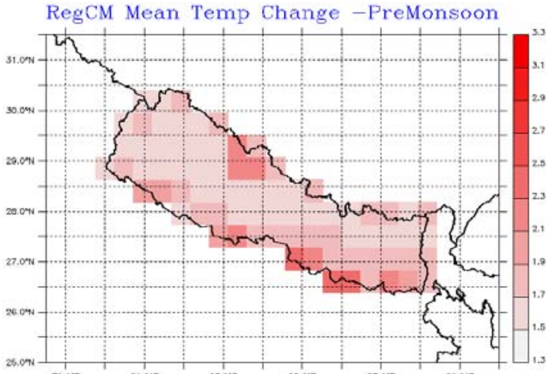


Figure 26a: Change in pre-monsoon mean temperature (°C), Nepal

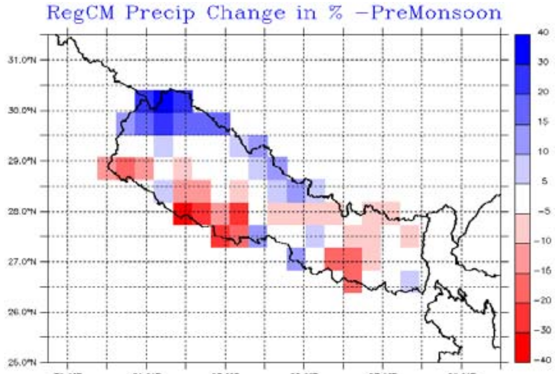


Figure 26b: Change in pre-monsoon mean precipitation (%), Nepal

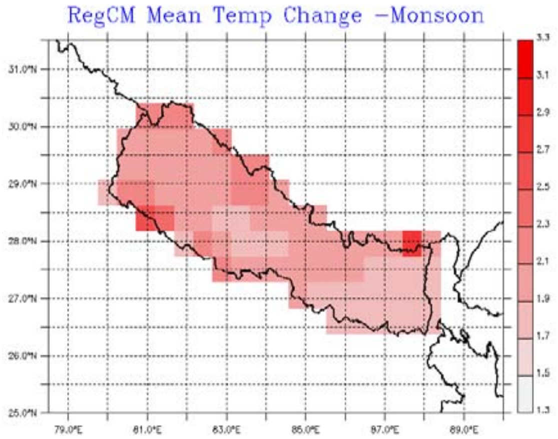


Figure 27a: Change in monsoon mean temperature (°C), Nepal

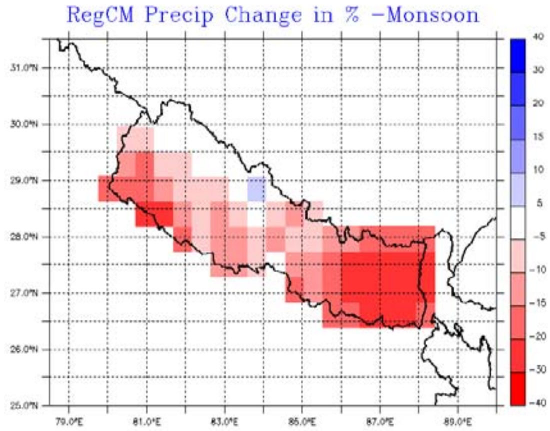


Figure 27b: Change in monsoon mean precipitation (%), Nepal

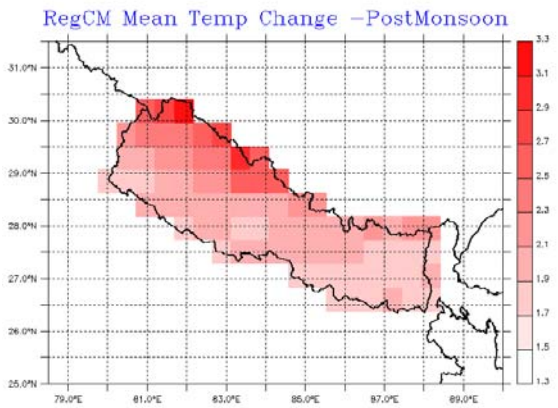


Figure 28a: Change in post-monsoon mean temperature (°C), Nepal

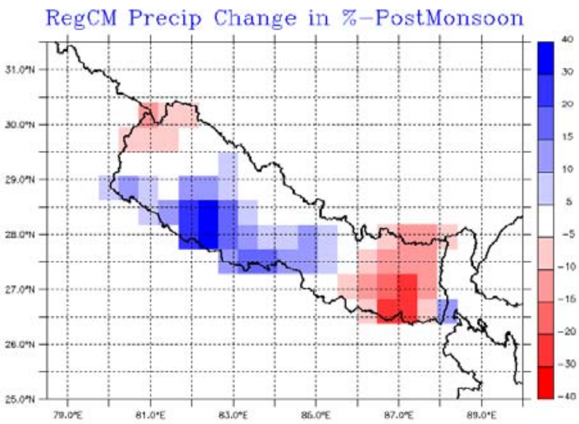


Figure 28b: Change in post-monsoon mean precipitation (%), Nepal

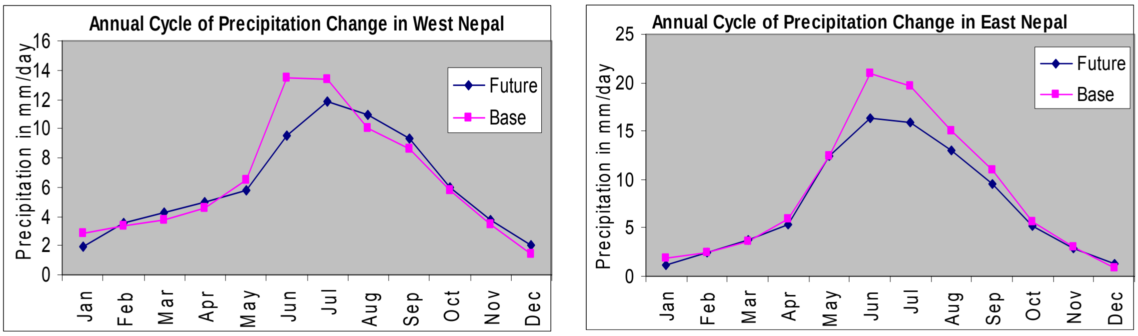


Figure 29: Comparison of Annual cycle of mean precipitation in West and East Nepal

Bangladesh: It was found that the baseline data (obtained from the Department of Meteorology) had too many outliers. An effort was therefore made to prepare clean datasets by identifying the outliers with the help of ClimDex model. A number of experiments were carried out for validation and calibration of RegCM3 over the South Asia region, in particular over Bangladesh. Using 60 km grid mesh for the South Asia window, Grell convection scheme and Arakawa-Schubert closure assumption, RegCM3 was run to simulate about 16 years of recent climate data which was then compared with the observed data sets for validation, in particular with respect to the diurnal behaviour of monsoon rainfall over Bangladesh and its neighboring areas.

The model was also used to simulate 6 tropical cyclones that developed in 1991, 1994, 1995, 1996, 1997 and 1999 in the Bay of Bengal. For the 1991 killer cyclone, the simulated cyclone track was very similar to the observed one. In the initial development stage of this cyclone, the surface pressure was 1002-1004 hPa and surface temperature was 27.5° C. The surface pressure then fell up to 996 hPa while the surface temperature fluctuated between 25.1-27.5° C. Precipitation structure and cyclonic wind fields were simulated well in the low pressure zone.

Based on a part of the above work, two team members obtained research-based M.Phil degrees from the Bangladesh University of Engineering and Technology. Their thesis topics were: (1) A validation of regional climate model simulation with observational data over Bangladesh (thesis submitted in May, 2006), and (2) Simulation of surface heat budget by RegCM3 model in South Asian region (thesis submitted in December, 2006).

3.2. Climate Change Impacts on Agriculture

3.2.1. Impacts on wheat and rice productivity in Pakistan

The impact of climate change on crop productivity in Pakistan was studied by considering the country divided into four agro-climatic zones, namely the Mountainous Region and the Sub-Mountainous Region in Northern Pakistan, and the Semi-arid Plains and the Arid Plains in Southern Pakistan. In these simulation experiments the climate change impacts were clearly discernable on two parameters: Growing Season Length (or Crop Life Cycle) and yield. As a result of increase in temperature, the Growing Season Length (GSL) of wheat was found to be shortened in all the four agro-climatic zones, with the reduction being the largest in magnitude in the Northern Mountainous region (see Table 15). For 5°C increase in temperature over the baseline temperature the GSL in the Northern Mountainous region decreased from its baseline value of 246 days to 194 days compared to 24-28 days decrease in other regions (from 161 to 133 days in the Sub-mountainous region, from 146 to 121 days in the Semi-arid plains and from 137 to 113 days in the

Arid plains). The simulation studies on rice were conducted only in the Semi-arid plains. Like wheat, the GSL of rice also decreased with increase in temperature over the baseline temperature: it decreased by 19 days (from 108 days to 89 days) for 5°C increase in temperature.

Table 15: Impact of rise in temperature on wheat growing season length in Northern and Southern parts of Pakistan

Temperature °C (increase over baseline)	Growing Season Length (Days)			
	Northern Pakistan		Southern Pakistan	
	Mountainous Region	Sub-Mountainous Region	Plains (Semi-arid)	Plains (Arid)
Baseline	246	161	146	137
1	232	155	140	132
2	221	149	135	127
3	211	144	130	123
4	202	138	125	118
5	194	133	121	113

Figure 30 shows the simulated impact of temperature increase over wheat yield in the four agro-climatic zones. The wheat yield decreases by about 4-5% for each °C rise in temperature in all the agro-climatic zones except the Northern mountainous region, where the yield increases initially at about 20% per °C rise in temperature but then flattens off for temperature increases of more tan 2°C above the baseline.

The behaviour of wheat yield In the Northern mountainous region shows that the required GSL for producing optimum yield is 190-200 days. The decrease in yield in other regions is obviously due to the shrinkage of GSL forcing the crop for early maturity, as the prevailing varieties of crops are not suited to high temperatures.

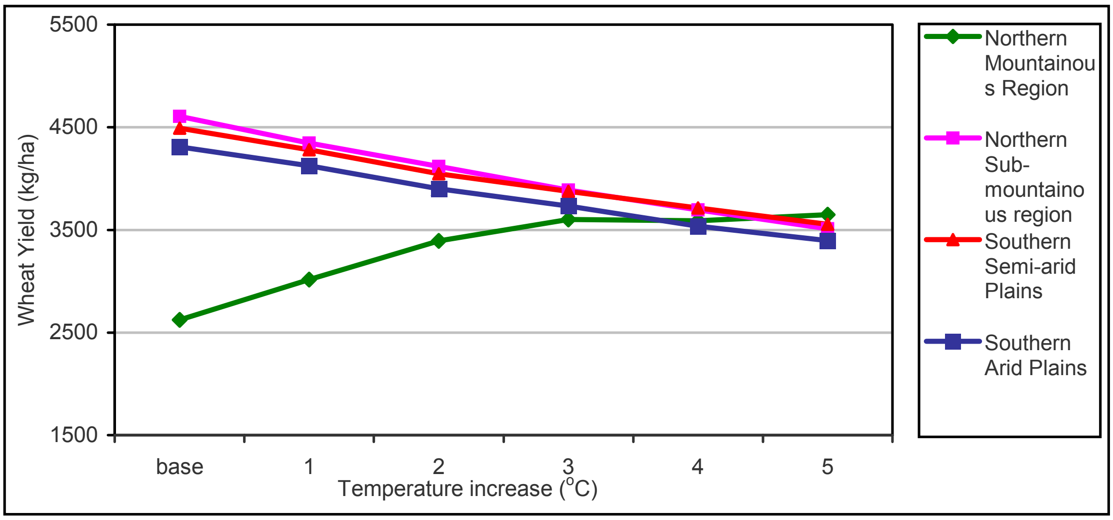


Figure 30: Effect of increase in temperature on wheat yields in different agro-climatic zones of Pakistan.

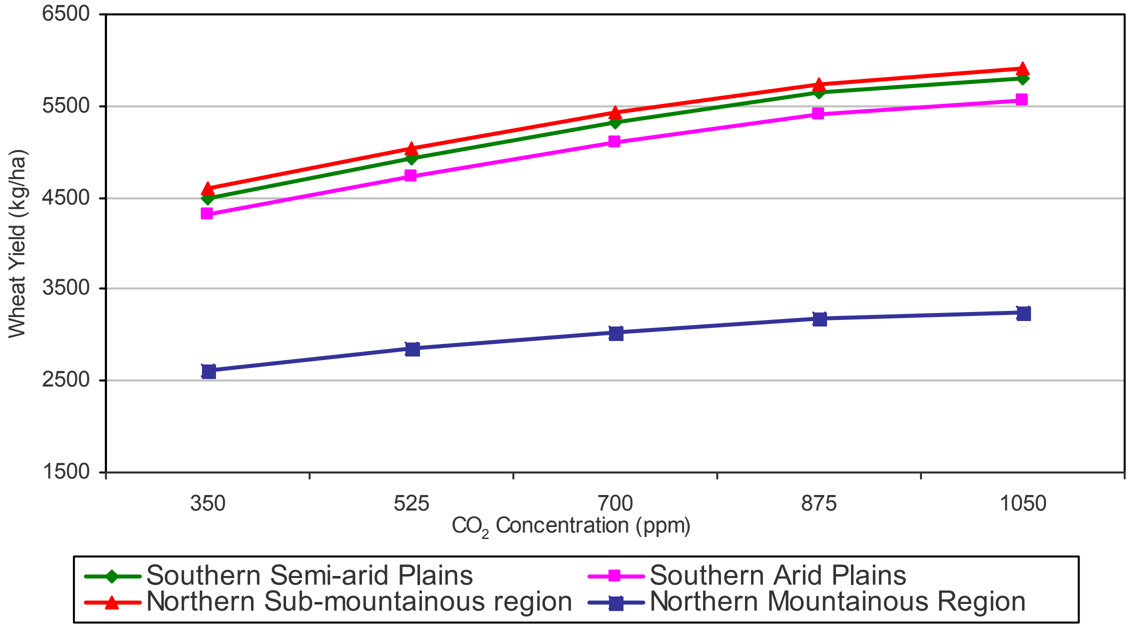


Figure 31: Effect of increase in CO_2 concentrations on wheat yields (other factors remaining constant).

The increase in atmospheric concentration CO_2 has a beneficial effect on crop yields due to its double fertilization effect: firstly, by virtue of being an essential constituent of photosynthetic process and secondly, by improving water use efficiency due to carbon isotope discrimination (Cure and Acock, 1986). The simulation experiments showed that the yields of both wheat and rice would increase with increase in CO_2 concentration, keeping other growth factors constant see Figure 31 for the case of wheat). Thus, in the case of future climate scenarios, the increase in CO_2 concentration can provide some relief to the depressive effect of temperature increase on yield.

The combined effect of rise in, both, temperature and CO_2 concentration on wheat yield revealed (see Figure 32) that, if CO_2 concentration were to increase from the baseline level of 375 ppm to up to 550 ppm, the enhanced level of CO_2 would not be able to help sustain the baseline yield in semi-arid areas for temperature increases beyond about 2.5°C. The rice, on the other hand appeared to be more sensitive to global warming compared to wheat as the fertilization effect of the increased CO_2 concentration up to 550 pm failed to maintain yield beyond about 1.5°C temperature increase (Figure 33). Similar results have been reported by Zhiqing et al. (1994).

Following the above investigations, the impacts of climate change on wheat and rice yields in Pakistan under the IPCC SRES scenarios A2 and B2 were worked out with the help of CERES models using the corresponding CO_2 concentration levels and the coarse resolution climate change projections for Pakistan and its selected sub-regions made by GCISC Climatology Section on the basis of the ensemble output of 6 coupled AOGCMs (see Section 3.1.2.). Figure 34 shows the simulated wheat yield in different agro-climatic zones of Pakistan in 2020s, 2050s and 2080s under A2 scenario. The yield is projected to increase in the northern mountainous region and decrease in other three regions throughout the time horizon. Table 16 provides quantitative information on the projected changes in yield in 2080s in A2 as well as B2 scenario. Although there will be a positive effect of climate change on wheat

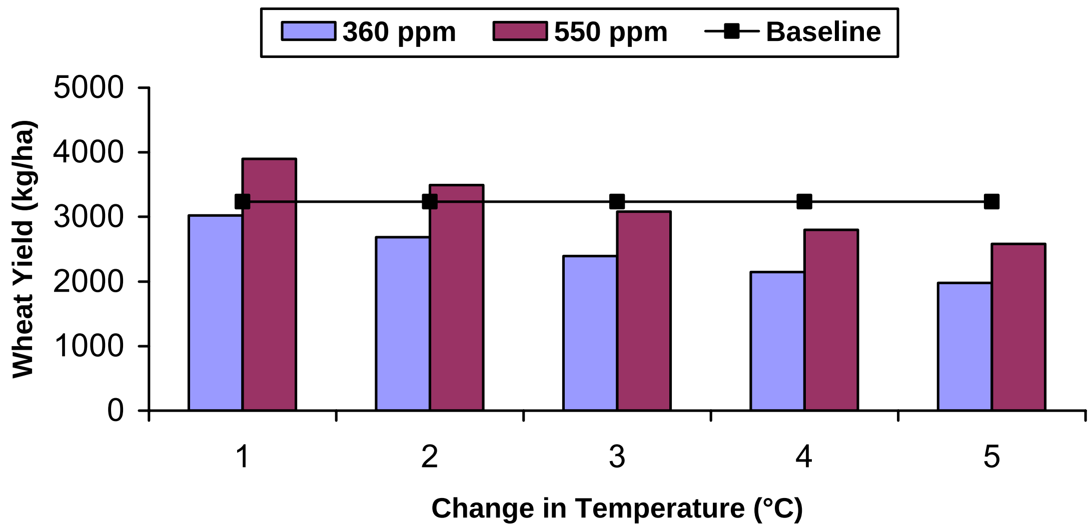


Figure 32: Impact of increase in temperature at two CO_2 levels on Wheat Yield in semi-arid areas, Pakistan

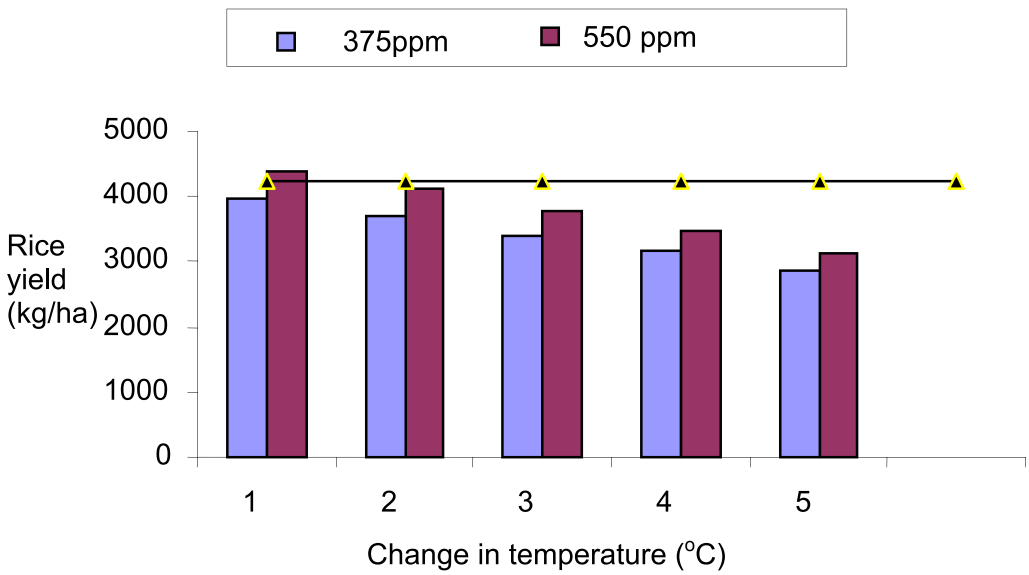


Figure 33: Impact of increase in temperature at two CO_2 levels on Basmati Rice Yield in the Semi-arid Plains region, Pakistan

yield in the northern mountainous region of Pakistan, given its meager share in the national wheat production, the overall impact of this increased productivity on the national level will be insignificant. The two main wheat producing areas, namely the semi-arid and arid plains, will experience a decrease in yield to the extent of 5-8 percent, resulting in an overall reduction of about 6 percent in the national wheat production in 2080s under both A2 and B2 scenarios.

The impact of climate change (including the change in CO_2 concentration level) under the above two scenarios on the yield of Basmati rice in southern semi-arid plains of Pakistan is shown in Figure 35. A decrease in yield in the order of 15% by 2080s is to be expected in either case due to the climate effect.

(For more information, please see Draft Reports DR-14 and DR-15 listed in Appendix IV and provided in the CD.)

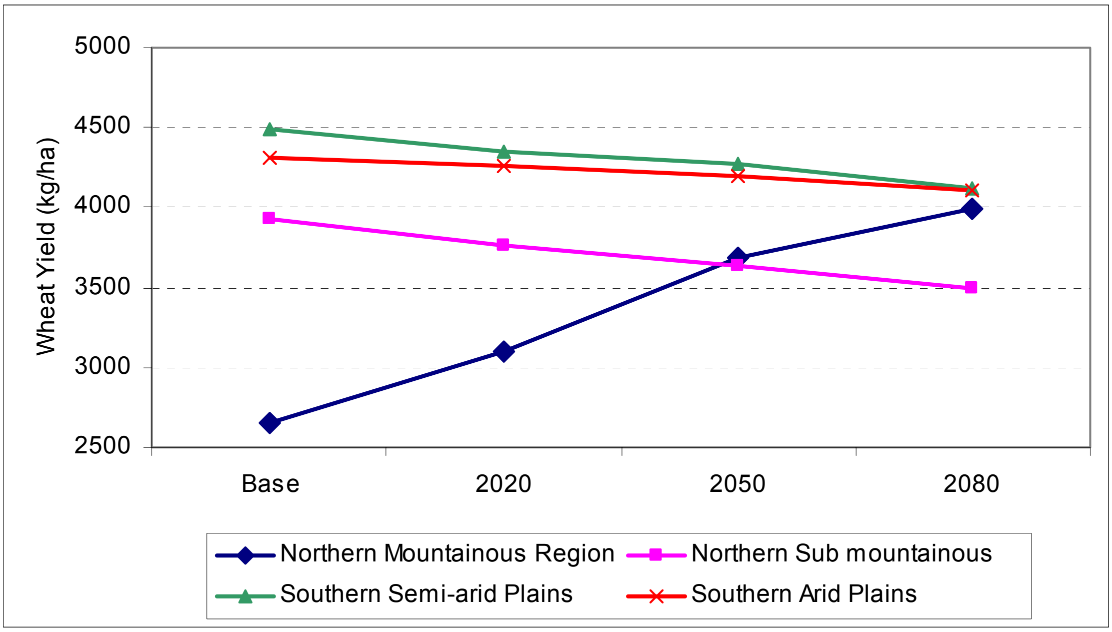


Figure 34: Projected wheat yield in different agro-climatic zones of Pakistan under A2 scenario.

Table 16: Impact of climate change on Wheat Production in Pakistan by 2080s under A2 and B2 Scenarios

Region	**% Share in National Production**	**Baseline Yield (kg ha^{-1})**	**% Change in yield in 2080s**	
			Scenario A2	**Scenario B2**
I (Northern Mountainous)	2	2658	+50	+40
II (Northern Sub-mountainous)	9	3933	-11	-11
III (Southern Semi arid Plain)	42	4306	-8	-8
IV (Southern Arid Plain)	47	4490	-5	-6
Pakistan	100	4326	-5.7	-6.4

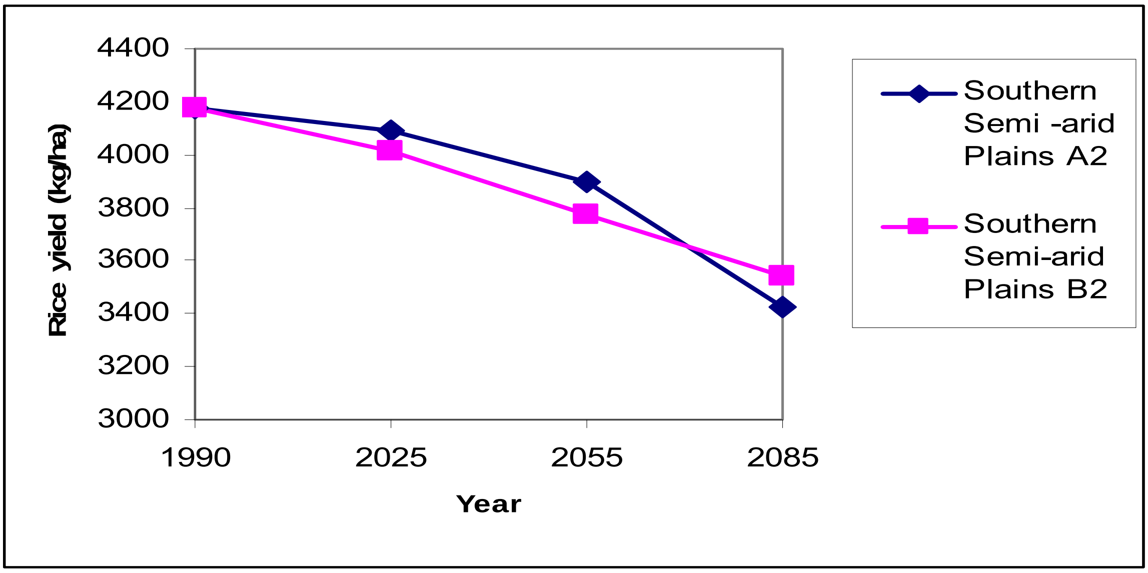


Figure 35: Projected Basmati rice yield in southern semi-arid plains of Pakistan under A2 and B2 scenarios.

3.2.2. *Impacts on productivity of rice, wheat, and maize in Nepal*

Three important crops rice, maize and wheat, which cover over 75% of the total production, were analyzed to examine the impact of increased atmospheric concentration of CO_2 combined with increased temperature and increased rainfall across the different agro-ecological belts of Nepal. The agro-ecological zones studied covered the Terai plains, the Hills and the Mountains. The scenarios included the following changes in the Ambient conditions in each zone:

(1) Increase in atmospheric concentration of CO_2 by 250 ppm
(2) As in (1) + 1° C rise in temperature
(3) As in (1) + 2° C rise in temperature
(4) As in (1) + 4° C rise in temperature
(5) As in (1) + 20% increase in rainfall
(6) As in (2) + 20% increase in rainfall
(7) As in (3) + 20% increase in rainfall
(8) As in (4) + 20% increase in rainfall

The impacts were studied on three parameters of each crop: yield and the phenology components, anthesis and physiological maturity. The corresponding results for rice are shown in Figures 36, 37 and 38 respectively.

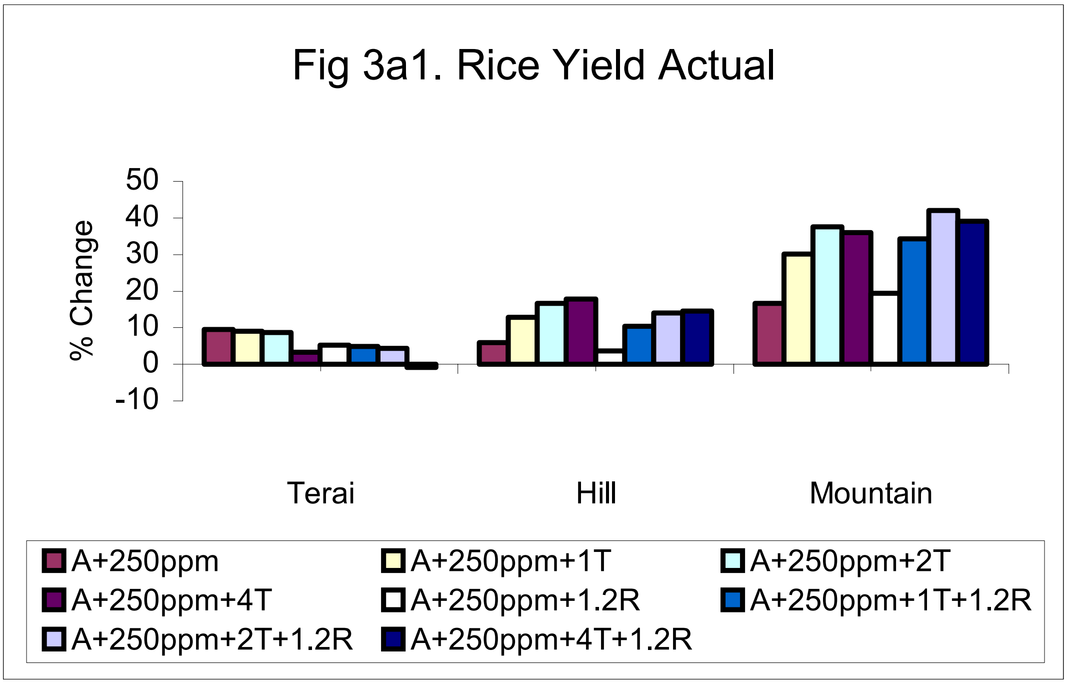


Figure 36: Variability of rice yield at different altitude regimes in Nepal as influenced by CO_2 climatic variability.

From Figure 36 it is seen that, compared to the baseline level, the rice yield increased by 9.5 % in the Terai plains, 5.9 % in the Hills and 16.6 % in the Mountains under the elevated CO_2 concentration of scenario 1 but the change dropped to 3.4 % level in the Terai plain, increased further to 17.9 % level in the hills and to 36.1 % level in the mountains at 4^0C rise in temperature, as in scenario 4. The change in yield however dropped to -0.8 % level in the Terai plains and to 14.6 % level in the Hills but increased to 39.1% level in the Mountains at 4 ^{0}C rise in temperature and 20 % increase in rainfall, as in scenario 8. Thus the rice yield in all the three zones benefited to varying extents under the above scenarios except the yield in the Terai plains under scenario 8, which decreased slightly - by about 1%. The mountains had the most beneficial impact in all the scenarios.

The phenology components, anthesis and physiological maturity, for the rice crop are presented in Figures 37 and 38 in terms of the change in number of days compared to the corresponding values under the Ambient conditions. The negative values in the graphs present the days earlier or fewer than those under the Ambient conditions.The CO_2 alone showed little or no impact on the phenology. The anthesis continued getting earlier and the maturity period getting shorter with the rise of temperature, the impacts being most marked in the mountains and least in the Terai plains. In scenario 4 the rice anthesis decreased by 5.4, 16.2 and 27.8 days, while the rice maturity decreased by 8.5, 32.5 and 98.5 days in the Terai plains, hills and mountains respectively. The 20% increase in rainfall (scenario 8) showed a slight enhancement effect but the changes were insignificant.

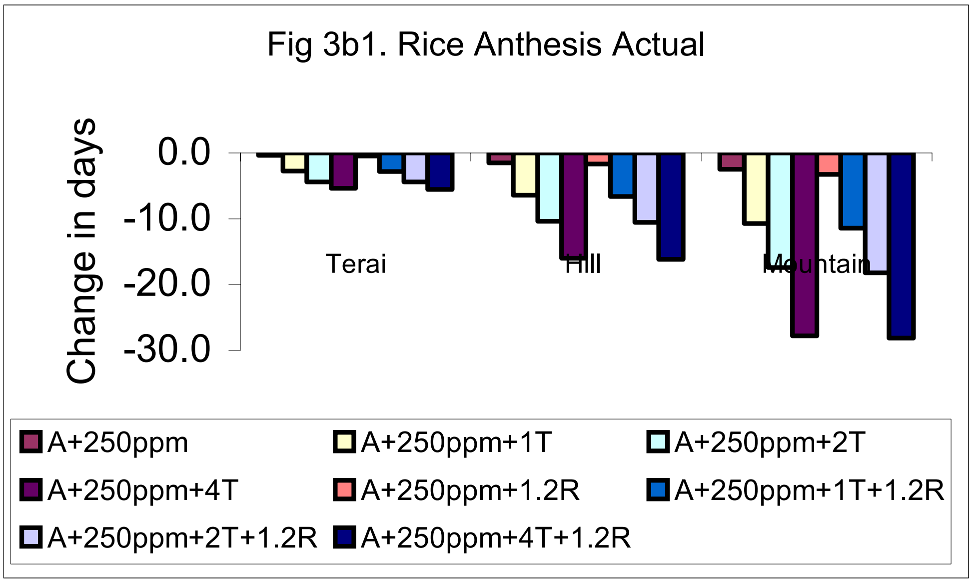


Figure 37: Variability of rice anthesis at different altitude regimes in Nepal as influenced by climatic variability.

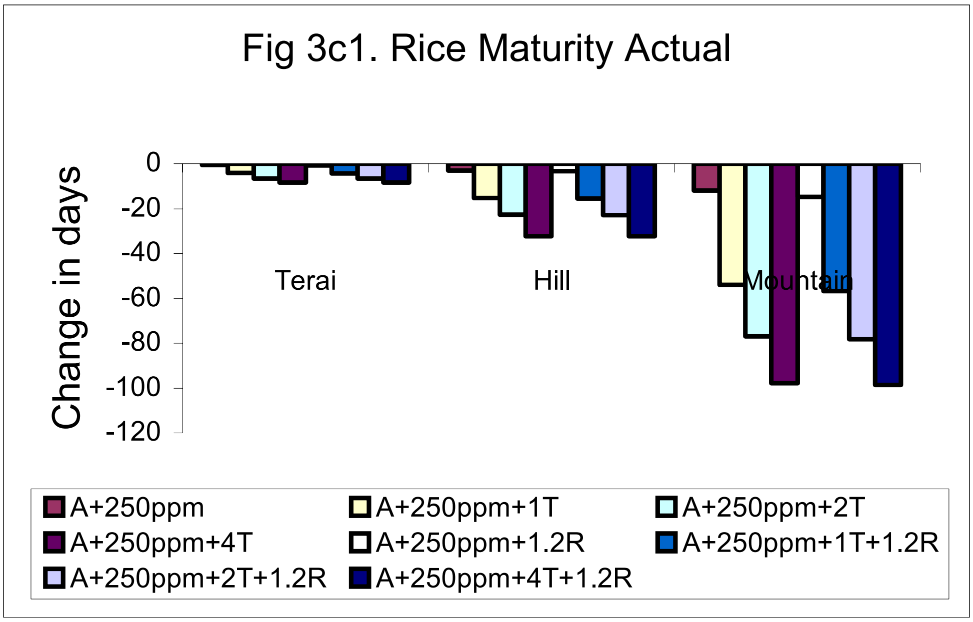


Figure 38: Variability of rice maturity at different altitude regimes In Nepal as influenced by climatic variability.

The simulation results for the yields of wheat and maize crops, similar to those for the rice crop, are presented in Figures 39 and 40. As seen in Figure 39, the wheat yield rose by 41.5 % in the Terai plains, 24.4 % in the hills and 21.2 % in the mountains under the elevated CO_2 (scenario 1). With temperature increase, the wheat yield rose in the mountains but dropped in in the Terai plains and the hills, reaching at 4 ^{0}C temperature increase (scenario 4) to levels of 33.3 % above the base line in the mountains, 1.8% below the baseline in the Terai plains and 5.3 % above the baseline in the hills. Thus the wheat response showed particularly favourable impact in the mountains. The additional rains (scenario 8) had a further favourable impact on the wheat yield in the mountains at all levels of temperature rise.

Maize is one of the important crops of Nepal. The CERES-based simulations showed that the elevated CO_2 had relatively small effect on raising the maize yield. Under the elevated CO_2 (scenario 1), the maize yield rose only by 9.0 % in the Terai plains, 4.9 % in the hills and 15.5 % in the mountains (Figure 40). However, with temperature increase, the maize yield declined in the Terai plains and the hills, reaching levels of 26.4 % and 9.3 % below the baseline respectively at 4^0C temperature rise (scenario 4). In the mountains the yield rose to 26.8 % above the baseline at 4^0C temperature increase. The additional rains(scenario 8) did not have much effect on the yields in the Terai plains and the hills but had marked favourable impact in the mountains.

(For more information, please see Draft Reports NDR-1 listed in Appendix IV and provided in the CD.)

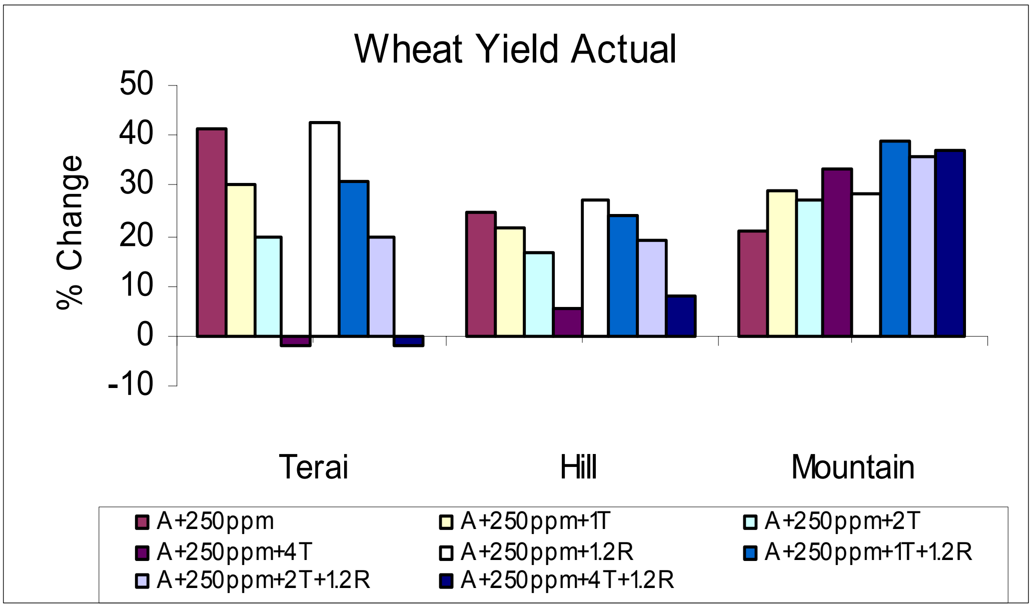


Figure 39: Variability of wheat yield at different altitude regimes in Nepal as influenced by different climatic scenarios.

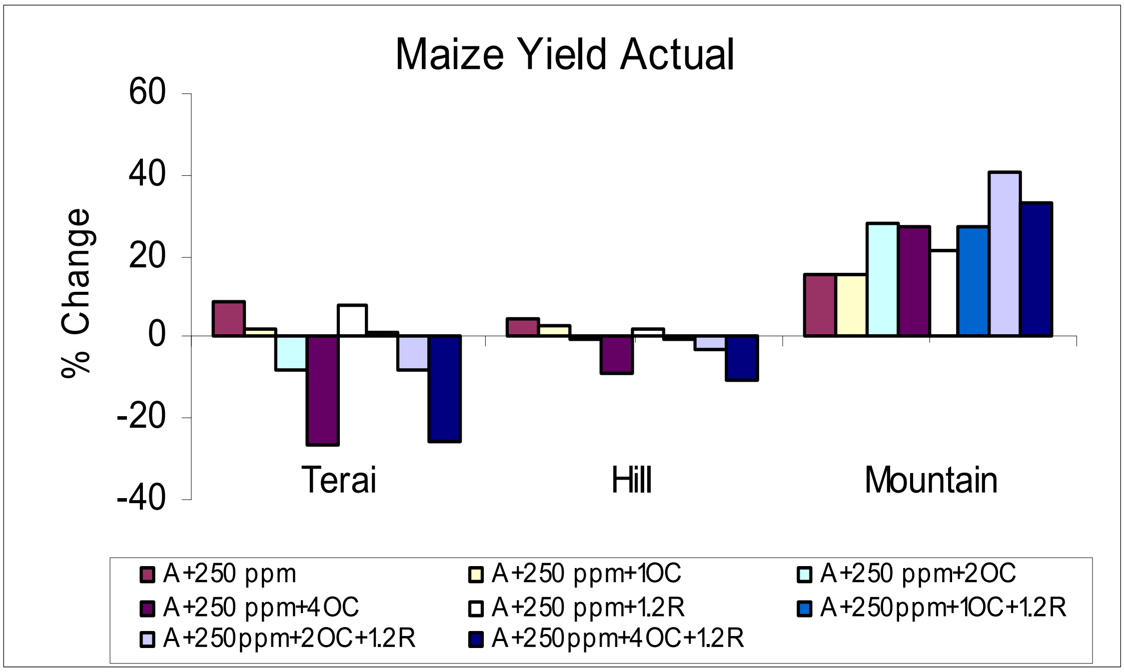


Figure 40: Variability of maize yield at different altitude regimes in Nepal as influenced by different climatic scenarios.

3.2.3. Use of CERES Models to Assess Adaptation Opportunities

Briefly reported here are the results of some CERES model based simulations carried out by the group in Pakistan to asses the suitability of certain adaptation measures to cope with the negative impacts of climate change:

(1) The effect of alteration in sowing date on growing season length (GSL) and yield of wheat crop was studied by trying 9 different sowing dates, starting from the first week of October to the last week of December at 10-day intervals, for the high mountainous and sub-mountainous areas. The results showed that the GSL, in the high mountainous areas, on the average decreased by 10-days for each 10-day delay in sowing dates and six days for each 1 ^{0}C rise in temperature. In the sub-mountainous areas the respective decreases in the GSL were 6 days and 3 days. The results (Figure 41) further showed that in the high-mountainous area, shortening of GSL has positive impact on yield because at prevalent temperatures wheat crop takes more than optimal time to complete its growth and development cycle. On the other hand, in sub-mountainous area, decrease in GSL was accompanied by a decline in yield as the current temperatures are probably close to the optimal temperatures required for obtaining maximum wheat yield.

(2) In view of the need to use the available irrigation water most effectively in the wake of reduced surface water availability on long term basis, the option of increasing the number of irrigations from the current practice of 3 irrigations to 5 by reducing the water per irrigation from 75 mm to 45 mm was tried on wheat. The results (Table 17) showed that increasing the number of irrigations to 5 by coinciding them with the critical growth stages of crown root initiation, tillering, late jointing, flowering and dough had positive effect on wheat yield at both the CO_2 levels and temperature increase scenarios (see Dang et al, 2007).

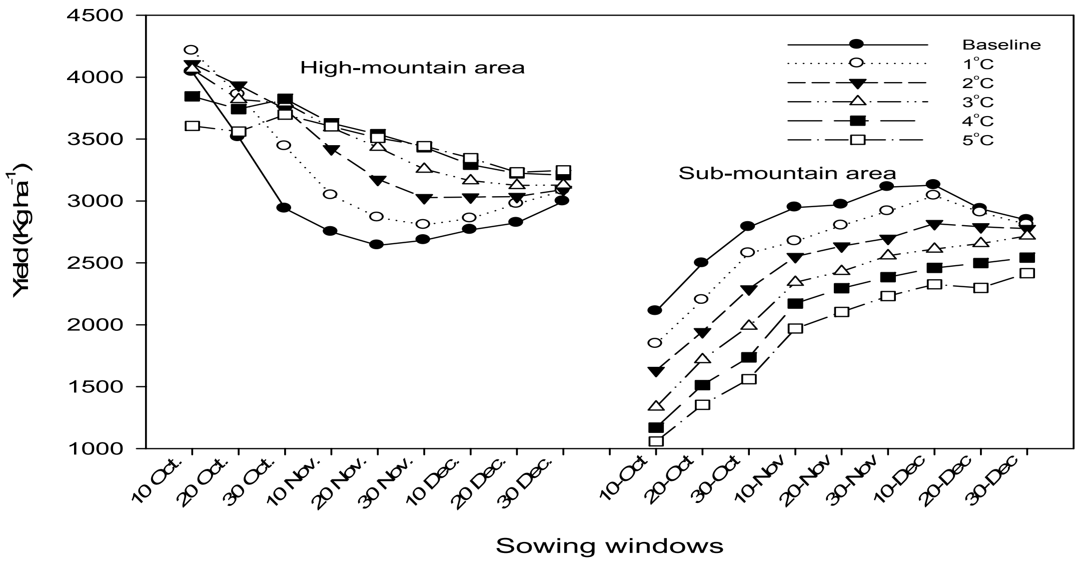


Figure 41: Wheat yield under various climate change and management scenarios in the study area, Pakistan

Table 17: Effect on wheat yield of providing 5 irrigations instead of 3 with no change in total water applied (Pakistan)

Temperature (C)	Semi Arid		Arid		Overall	
	CO_2 Level (ppm)		CO_2 Level (ppm)		CO_2 Level (ppm)	
	360	550	360	550	360	550
1	4441	5077	3467	4159	3856	4526
	(24.60)	(42.44)	(52.73)	(83.20)	(38.37)	(62.39)
2	4096	4699	3133	3783	3518	4150
	(14.92)	(31.86)	(38.00)	(66.66)	(26.22)	(48.89)
3	3715	4294	2816	3435	3175	3779
	(4.23)	(20.49)	(24.05)	(51.32)	(13.94)	(35.58)
4	3395	3933	2590	3197	2912	3491
	(-4.74)	(10.35)	(14.10)	(40.83)	(4.49)	(25.27)
5	3191	3706	2424	3031	2731	3301
	(-10.47)	(3.99)	(6.78)	(33.54)	(-2.02)	(18.46)

*Figures in parentheses are percentage differences from respective Baseline Yield

(3) Various CERES-Rice simulations were carried out to study the adaptation measures for coping with the negative impacts of climate change on rice yields.

(i) As paddy yield per unit area is highly dependent on the method of sowing/planting of rice at appropriate time, the optimal planting dates for Basmati Super, an aromatic fine-grain cultivar, were determined for the semi-arid areas of Punjab, Pakistan, under temperature increases from 1 to 5C. The rice yield increased by 3% on 20th July transplanting as compared to 5 July (Table 18) but the corresponding increase in growing season length (110 to 114 days) might disturb Rice-Wheat cropping system, that’s why, 5th July transplanting is advised under prevalent climatic conditions. Further delay in transplanting beyond 20th July decreased rice yields by 1%. Late transplanting (20th July) can serve as an adaptation strategy to sustain baseline yield under temperature rise up to 2 °C at CO_2 level of 550 ppm provided other management practices employed are kept the same.

(ii) The feasibility of dry seeding under semi arid conditions of Punjab, Pakistan as an adaptation strategy was assessed by comparing its yield performance with the yield of transplanted rice using the CERES-Rice model. The results showed that Direct Dry Seeding of rice offered a useful opportunity for improving water use efficiency (WUE). The WUE increased from 2.91 to 3.68 kg/m^3 in Faisalabad district and from 3.10 to 3.82 kg/m^3 in Sheikhupura districts, by reducing the water inflow requirements during land preparation and transplanting, thus conserving about 25% of irrigation water (see Mann et al. 2004).

Table 18: Simulated grain yields under optimal growing season (Pakistan)

Increase in Temperature (°C) (above Baseline, at 550 ppm CO_2 level)	Yield (kg/ha) with transplanting dates			
	20-Jun	05-Jul	20-Jul	05-Aug
Baseline	4614	4601	4730	4645
1	4411	4400	4521	4377
2	4088	4077	4176	3987
3	3715	3697	3747	3602
4	3327	3288	3324	3194
5	2947	2885	2854	2745

(iii) Using the CERES-Rice model, the feasibility of direct dry seeding of rice instead of transplanting it is also being assessed under the semi-arid conditions of Punjab, Pakistan as an adaptation strategy in case of shortages of irrigation water. However, in view of the resulting reduction in yield, the results as yet are not quite clear.

(For more information, please see Draft Reports DR-16 listed in Appendix IV and provided in the CD.)

3.3. Climate Change Impacts on Water Resources

3.3.1. Application of Watershed Models

Pakistan: As mentioned earlier, the watershed simulation studies conducted in Pakistan were mainly based on the use of DHSVM and UBC models. The results are summarised below.

DHSVM was applied to the Siran River basin which has an area of 1060 sq. km up to Phulra gauging site. The elevation of the Siran watershed ranges between 834 m and 4199 m and the terrain comprises two valleys: Pakhli and Chattar surrounded by moderate to steeply sloping mountains. The calibration and statistical results are shown in Figures 42, 43 and Table 19 respectively. The model performed quite well in this relatively small basin. Presently DHSVM is being calibrated for Indus River at Besham Qila (the flow observation site just above the Tarbela reservoir).

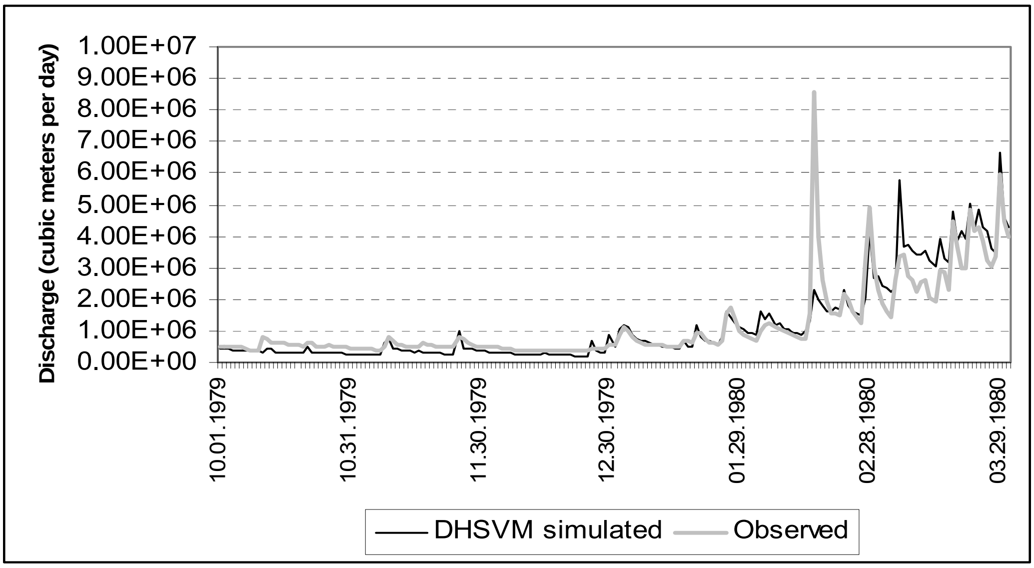


Figure 42: DHSVM Simulated and observed hydrographs for Siran River(winter months 1979 and 1980)

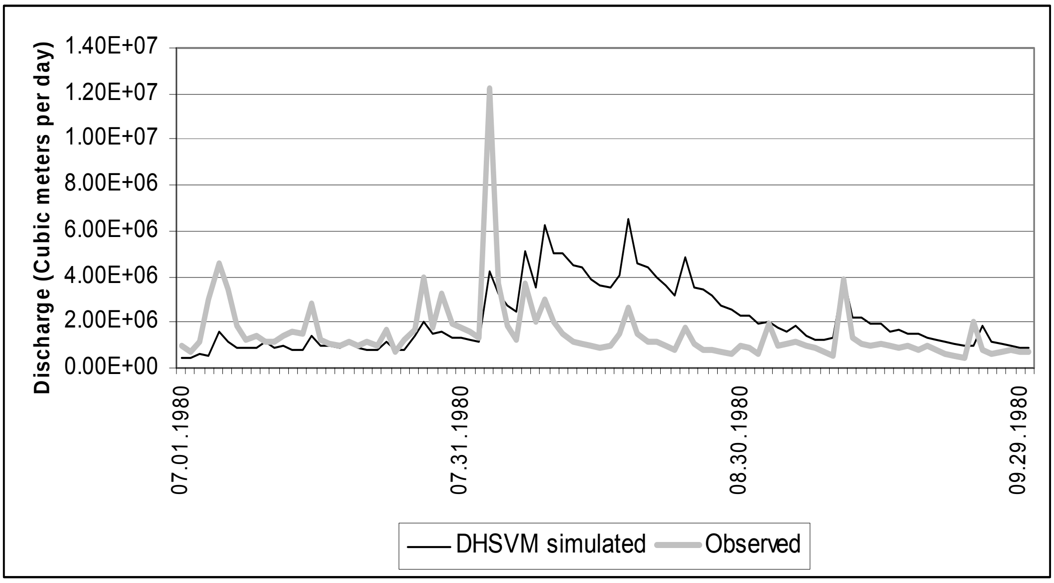


Figure 43: DHSVM Simulated and observed hydrographs for Siran River (Monsoon 1980)

Table 19: Overall and seasonal accuracies of DHSVM outputs for Siran River, Pakistan (1979 and 1980).

Season / Period	Simulated (million m^3)	Observed (million m^3)	Accuracy (%)
March 1979 to December 1980	881	997	88.4
Winter 1979-1980	220	221	99.7
Monsoon 1979	101	110	91.9
Monsoon 1980	140	137	62.3

UBC watershed model was used to simulate the daily steam flow of six watersheds in Pakistan having different hydrological regimes: Siran River at Phulra (fed by monsoon rains), Hunza River at Daniyour (fed mainly by glacier melt and snowmelt), Astore River at Doyian (mainly snow fed), Jhelum River at Azad Pattan (fed by snowmelt, rainfall and glacier melt), Kabul River at Nowshera (fed mainly by snowmelt and glacier melt) and Indus River at Besham Qila (just above Tarbela Reservoir) (fed by snowmelt, rainfall and glacier melt). Figures 44 and 45 show respectively the calibration and validation of the UBC model for Siran River Basin. The corresponding information about the time periods covered in calibration and validation simulations and the model performance is provided in Table 20.

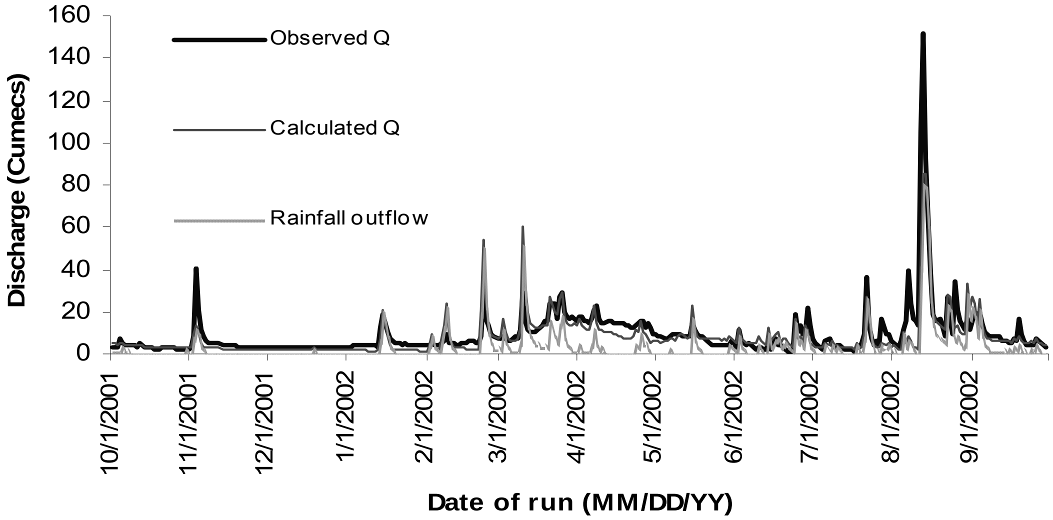


Figure 44: Calibration of the UBC watershed model for Siran River Basin

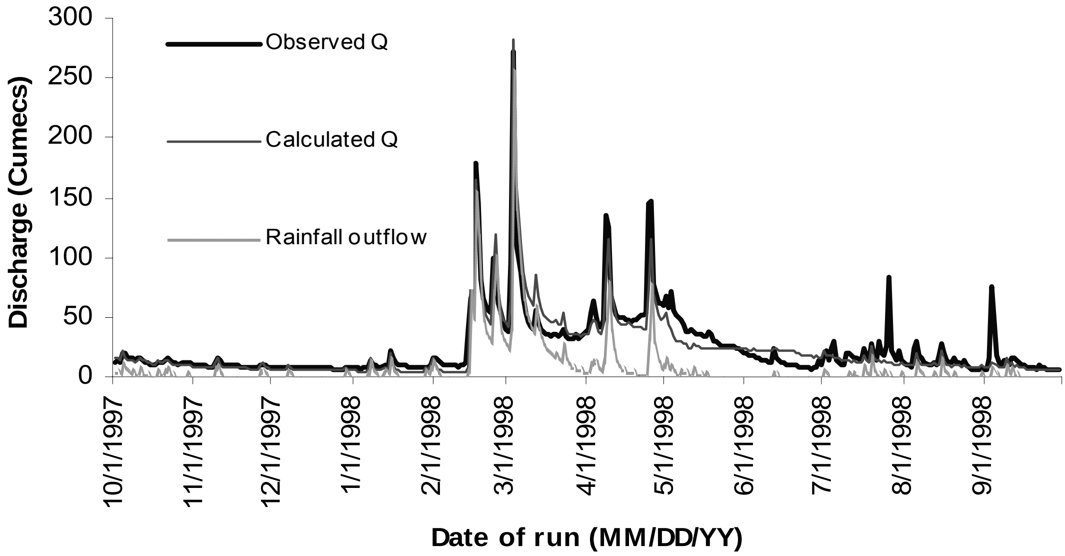


Figure 45: Validation of the UBC watershed model for Siran River Basin

Table 20: Calibration and Validation statistics of the UBC watershed model for Siran River Basin, Pakistan

Hydrologic years	Nash-Sutcliffe efficiency (Eff)	Coefficient of determination (R^2)	Runoff volume diff. (% DV)	Mean observed flow (m^3/s)	Mean simulated flow (m^3/s)
Calibration period					
1999-2000	0.60	0.63	2.87	10.79	11.10
2000-2001	0.66	0.82	4.17	7.43	7.74
2001-2002	0.68	0.69	-13.38	9.27	8.03
Whole period (1999-2002)	0.66	0.69	-2.18	9.16	8.96
Validation period					
1995-1996	0.74	0.80	15.31	22.14	25.53
1996-1997	0.57	0.65	-11.47	21.62	19.14
1997-1998	0.85	0.85	-7.81	24.58	22.66
1998-1999	0.73	0.77	8.60	11.51	12.50
Whole period (1995-1999)	0.74	0.76	0.00	19.96	19.96

The model efficiency values listed in column 2 of Table 20 were evaluated by using the Nash-Sutcliffe efficiency test defined as:

$$Eff = 1 - \frac{\sum_{i=1}^{n} \left(Qobs_i - Qsim_i\right)^2}{\sum_{i=1}^{n} \left(Qobs_i - \overline{Qobs}\right)^2}$$

Where, $Qobs_i$ is the observed flow on day *i*, $Qsim_i$ is the simulated flow on day *i*, $\overline{Qobs}$ is the average observed flow and *n* is the number of days for the simulation period. The range of *Eff* lies between 1 (perfect fit) and -∞. Physically, *Eff* is the ratio of the Mean Square Error (MSE) to the variance in the observed data, subtracted from unity.

The calibration of the UBC model for Hunza River Basin and Indus River Basin is shown in Figures 46 and 47 respectively, while Tables 21 and 22 list the corresponding information on time periods used for calibration and validation and about the model performance. From these studies it is concluded that, with proper calibration, the UBC model can simulate reasonably well the watershed behaviour of various small and large basins of Pakistan involving main contributions from a variety of mix of rainfall, snowmelt and glacier melt.

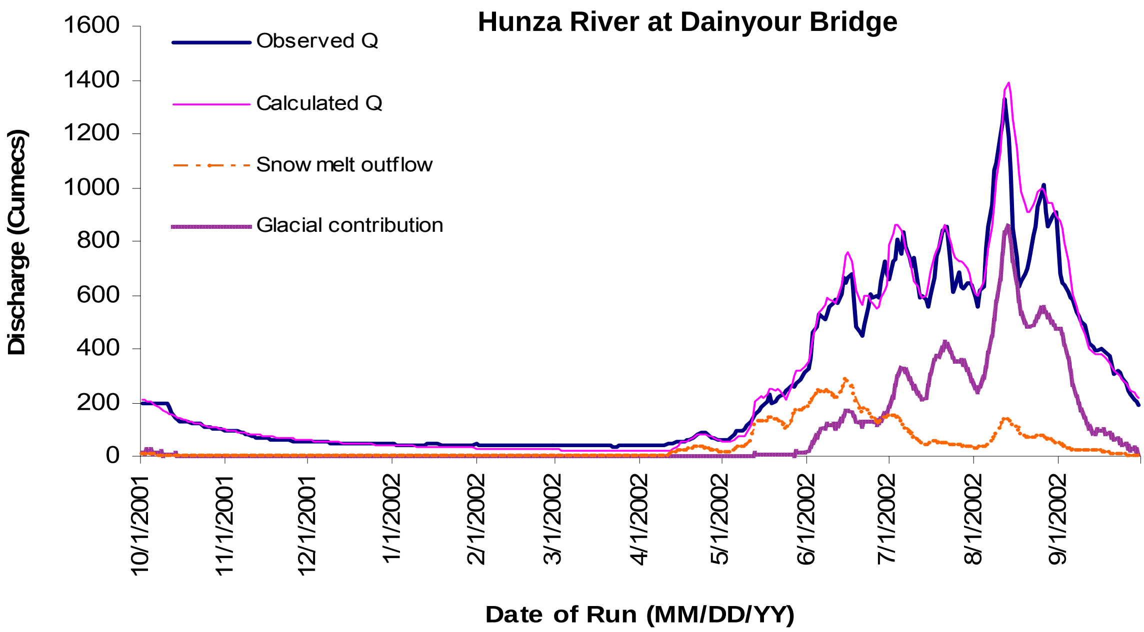


Figure 46: Calibration of the UBC watershed model for Hunza River Basin

Table 21: Calibration and Validation statistics of the UBC watershed model for Hunza River Basin, Pakistan

Hydrologic years	**Nash-Sutcliffe efficiency (Eff)**	**Coefficient of determination (R^2)**	**Runoff volume diff. (% DV)**	**Mean observed flow (m^3/s)**	**Mean simulated flow (m^3/s)**
Calibration period					
1999-2000	0.89	0.89	1.53	282.58	286.90
2000-2001	0.90	0.91	-10.49	353.78	316.68
2001-2002	0.95	0.97	4.59	265.42	277.59
Whole period (1999-2002)	0.91	0.91	-2.28	300.58	293.72
Validation period					
1995-1996	0.89	0.89	2.53	256.85	263.34
1996-1997	-0.49	0.93	70.07	199.55	339.37
1997-1998	0.85	0.86	-11.34	327.23	290.12
1998-1999	0.87	0.88	3.82	313.66	325.63

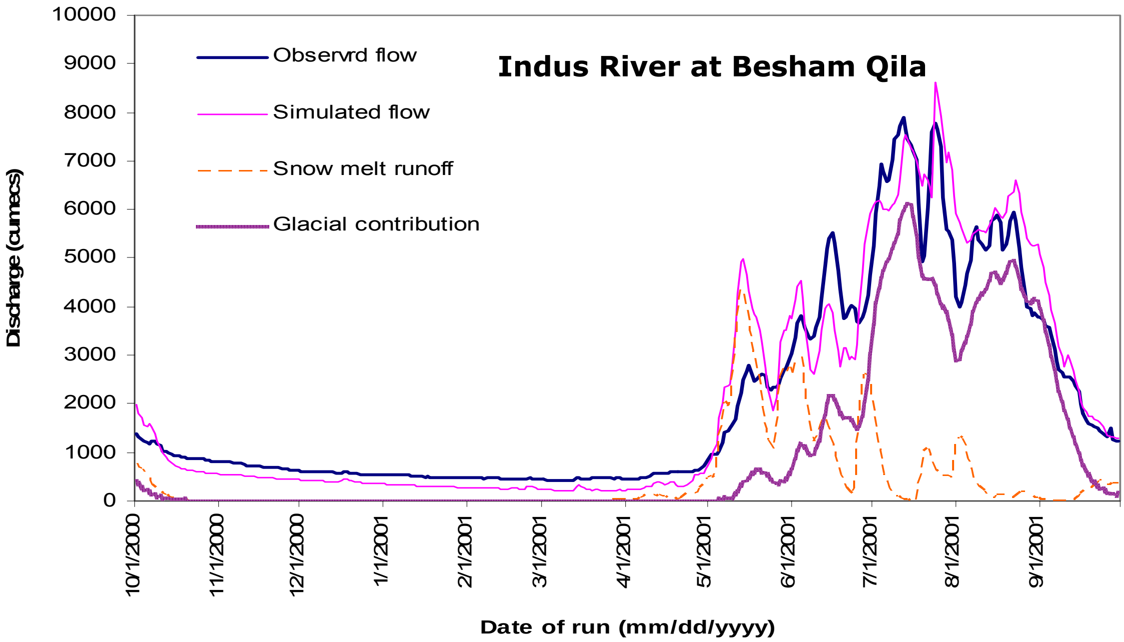


Figure 47: Calibration of the UBC watershed model for Indus River Basin

Table 22: Calibration and validation statistics of the UBC Watershed model for Upper Indus Basin, Pakistan

Hydrologic years	**Nash-Sutcliffe efficiency (Eff)**	**Coefficient of determination (R^2)**	**Runoff Volume diff. (% DV)**	**Mean Observed flow (m^3/s)**	**Mean Simulated flow (m^3/s)**
Calibration period					
1999-2000	0.78	0.79	-5.70	2263.82	2134.71
2000-2001	0.91	0.93	2.16	2031.50	2075.44
2001-2002	0.90	0.91	4.04	2193.06	2281.57
2002-2003	0.87	0.88	-6.60	2597.73	2426.21
2003-2004	0.84	0.90	10.39	2116.27	2336.11
Whole period (1999-2004)	0.86	0.87	0.32	2258.09	2265.42
Validation period					
1995-1996	0.89	0.90	-8.74	2484.32	2267.23
1996-1997	0.81	0.85	6.55	2002.84	2134.11
1997-1998	0.86	0.87	-10.12	2470.48	2220.33
1998-1999	0.87	0.88	-6.08	2872.37	2697.77
Whole period (1995-1999)	0.87	0.87	-5.16	2484.96	2356.78

Following its calibration for the Indus River Basin, the UBC model was used to make a preliminary assessment of the combined effect of deglaciation and temperature rise on the flows of Indus River at Bisham Qila (just above Tarbela reservoir). For this a comparison was made between the simulated flows in the baseline period (1995-2004) with those under the influence of a hypothetical scenario in which the temperature was assumed to have increased uniformly by 3 ^{0}C throughout the year while the glacier area was assumed to have shrunk to 50% of the baseline area. The model was applied to work out the overall river flows as well as the individual contributions arising from glacier melt, snow melt and rainfall. The results are shown in Figure 48. It is found that not only the hypothetical scenario would lead to about 15% reduction in annual flows, it would also result in a considerable alteration of the intra-annual pattern of flows. Because of the elevated temperature the glacier melt will start contributing early in the season, making more water available during the spring, but the summer flows will decrease considerably due to the reduced size of the glacier. Efforts are now underway to generate flow patterns over the next several decades using the temperature and precipitation scenarios worked out by the GCISC Climatology Section inline with the IPCC SRES scenarios.

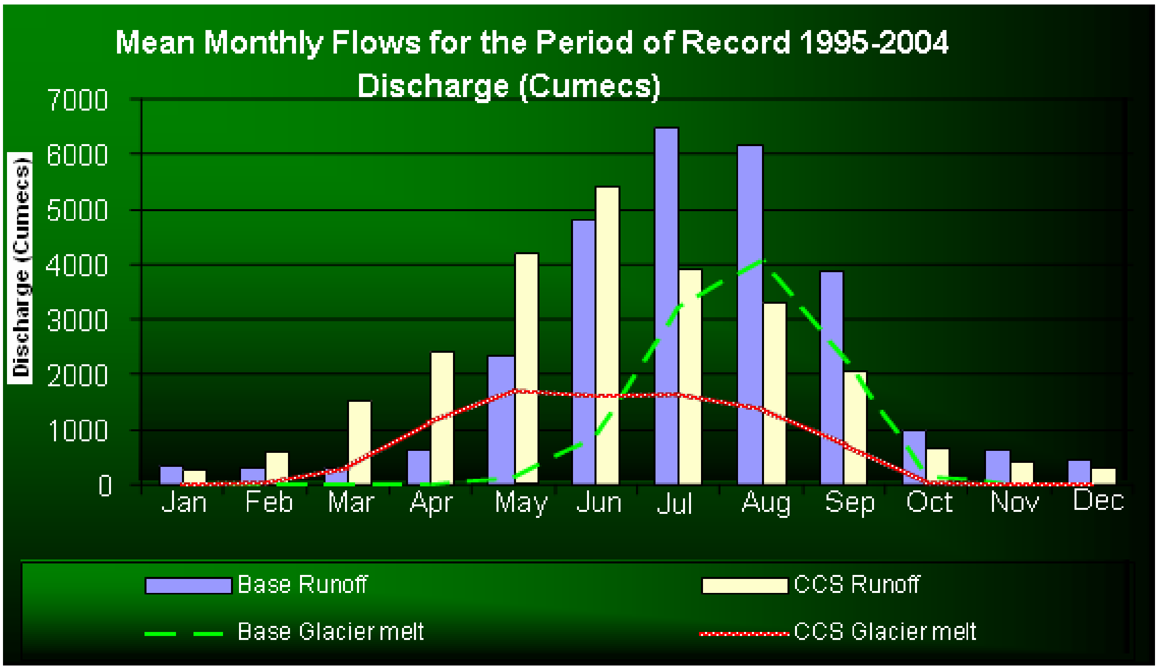


Figure 48: **UBC** simulated mean monthly flows of Indus River under the baseline (1995-2004) conditions and under the influence of a hypothetical climate change scenario (CCS)

(For more information, please see Draft Reports DR-11 listed in Appendix IV and provided in the CD.)

Nepal: The watershed models WatBal, HFAM and BTOPMC were calibrated and validated for Narayani River Basin with the help of the observed hydrological discharge records. The whole study basin was divided into five sub-basins taking the selected gauging site of the river as the outlet of each sub-basin. The calibration of the model was carried out by running the model several times for the period 1993-1997, each time adjusting the values of block parameters so as to reproduce the water balance of the whole basin. Then the parameters were further adjusted and tuned to get the simulated hydrograph closer to the observed hydrograph. Validation of the model was performed for the period 1998-2001 using the final set of parameters obtained in the calibration process. The simulated hydrographs yielded from validation were found close to the observed hydrographs. Figures 49 and 50 respectively show the calibration and validation outputs of the BTOPMC model.

The calibrated models were then used to estimate the changes in Narayani river discharges for various climate change scenarios involving different combinations of temperature and precipitation. The results are presented in Table 23 using the following scenario notations:

- P indicates precipitation and the subscript represents percentage increase in precipitation over the baseline value; and
- T indicates Temperature and the subscript shows the rise in temperature (in degrees Centigrade) over the baseline value.

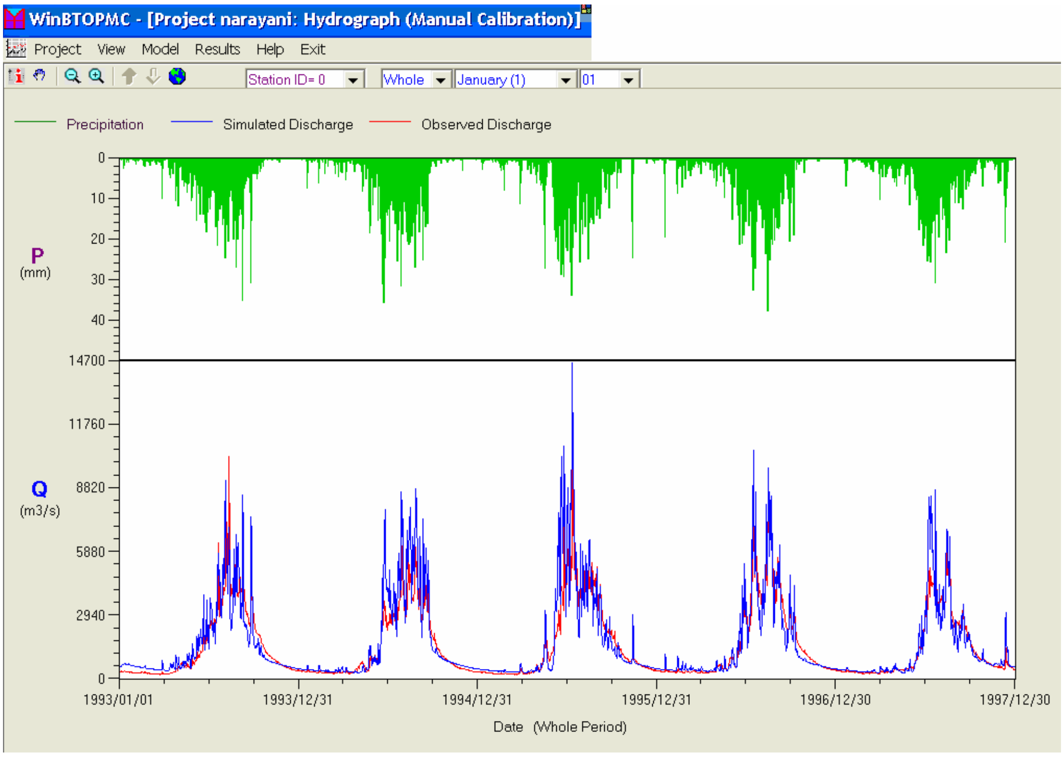


Figure 49 : BTOPMC model output for the calibration of the Narayani River flows

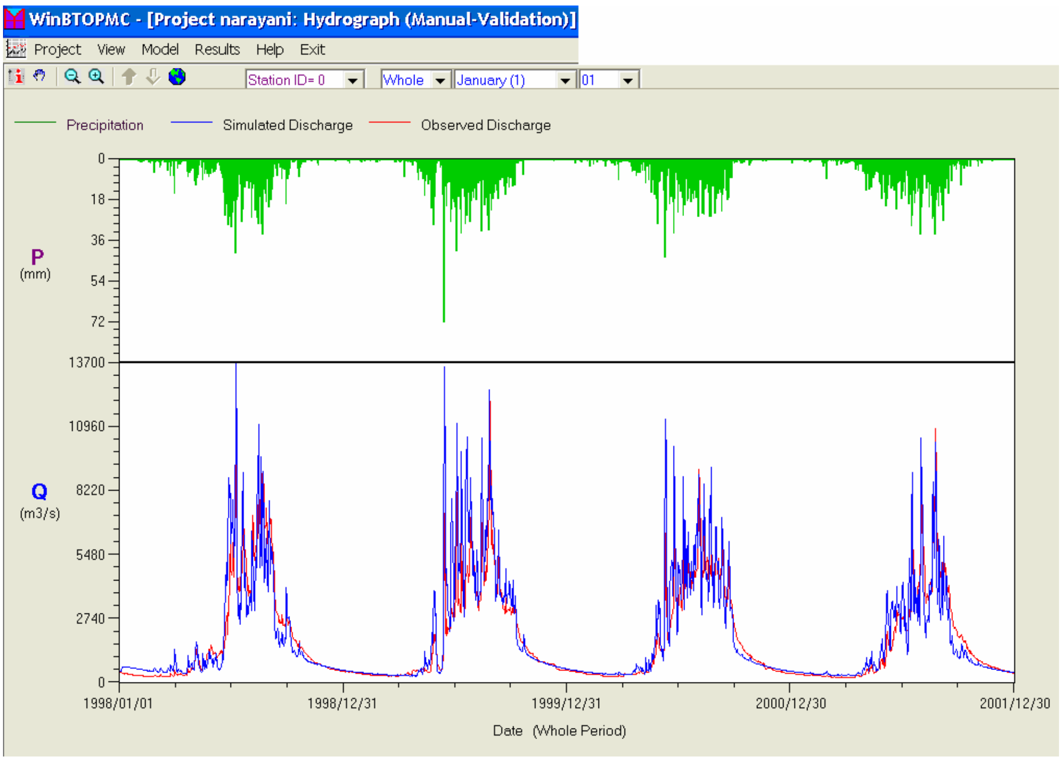


Figure 50: BTOPMC model output for the validation of the Narayani River flows

Table 23: Estimated changes in Narayani river discharges (Nepal) for different climate change scenarios obtained with WatBal, HFAM and BTOPMC models

River Flow	Average			Maximum			Minimum		
WatBal									
	T_0	T_1	T_4	T_0	T_1	T_4	T_0	T_1	T_4
P_0	1.00	1.00	0.99	1.00	1.00	0.99	1.00	1.00	1.00
P_{10}	1.10	1.10	1.09	1.13	1.13	1.11	1.02	1.02	1.02
P_{20}	1.20	1.20	1.19	1.26	1.26	1.24	1.03	1.03	1.03
P_{50}	1.52	1.52	1.50	1.68	1.68	1.66	1.11	1.11	1.11
HFAM									
	T_0	T_1	T_4	T_0	T_1	T_4	T_0	T_1	T_4
P_0	1.00	0.99	0.97	1.00	1.00	0.99	1.00	1.00	1.00
P_{10}	1.15	1.14	1.13	1.16	1.16	1.16	1.00	1.00	1.00
P_{20}	1.31	1.30	1.28	1.32	1.32	1.32	1.00	1.00	1.00
P_{50}	1.78	1.78	1.76	1.80	1.80	1.80	1.00	1.00	1.00
BTOPMC									
	T_0	T_1	T_3	T_0	T_1	T_3	T_0	T_1	T_3
P_0	1.000	1.007	1.014	1.000	1.006	1.017	1.000	0.962	0.769
P_{20}	1.239	1.252	1.268	1.385	1.422	1.478	1.047	1.026	0.974
P_{50}	1.608	1.624	1.653	1.994	2.053	2.132	1.094	1.080	1.041

A comparison of results given in Table 23 shows that the simulated impacts are most consistent in the case of the lumped WatBal model and least consistent in the case of the distributed BTOPMC model, particularly when the temperature is changing. The model results are mutually more consistent with respect to changes in precipitation only.

(For more information, please see Draft Reports NDR-3 listed in Appendix IV and provided in the CD.)

3.3.2. Study of Glacier Retreats

Using appropriate GIS software, measurements were made on the satellite images of Biofo glaciers taken in October 19992 and October 2000 and the area, length and width of the main glacier were calculated. Assuming no significant errors over and above those arising from the resolution of the satellite imagery, these measurements indicate a decrease in the length of Biafo glacier between 1992 and 2000 by 0.192 ± 0.043 km, an increases in the glacier area by 1.52 ± 2.55 km², and an increase in the glacier width by 0.033±0.043 km. This preliminary exercise establishes that, given sufficient high resolution data, the above approach may be usefully employed to obtain meaningful information about the temporal changes in the alpine glaciers of Western Himalayas over the last few decades. (For more information, please see Draft Reports DR-12 listed in Appendix IV and provided in the CD.)

3.3.3. Statistical Downscaling of GCM based Climate Scenarios

The Hadley Centre GCM data was statistically downscaled at the station level using the regression technique. The downscaled data was then interpolated for generating high resolution temperature and precipitation maps using the Backward Elimination method. Using these maps, the temperature and precipitation values up to 2099 in three different parts of Pakistan viz. Northern area (34° N-37° N), Central area (30° N-34° N) and Southern area (23° N-30° N), were worked out. The 30-year averaged results on monthly basis for Northern area of Pakistan covering the periods (2010-2039), (2040-2069) and (2070-2099) relative to the corresponding baseline values are shown in Tables 24 (a, b) and Figure 51 (a, b). It is now planned to refine this approach and compare the results obtained through dynamic downscaling of the same GCM data. (For more information, please see Draft Reports DR-9 listed in Appendix IV and provided in the CD.)

Table 24: Statistically downscaled projected changes in (a) Temperature (°C) relative to (1974-2000) base period, and (b) Precipitation (mm) relative to (1961-2000) base periods in Northern Region of Pakistan.

(a) Temperature change (°C)

North	Change up to 2039	Change up to 2069	Change up to 2099
Jan	2.55	4.39	6.15
Feb	2.70	4.88	5.92
Mar	3.15	4.33	6.10
Apr	1.74	2.76	3.68
May	1.64	4.23	6.66
Jun	1.39	2.93	6.61
Jul	0.33	2.16	3.84
Aug	-0.42	1.51	3.62
Sep	-0.04	1.67	4.05
Oct	1.60	3.24	4.58
Nov	2.17	3.62	4.99
Dec	1.80	3.15	4.51

(b) Precipitation change (mm)

North	Change up to 2039	Change up to 2069	Change up to 2099
Jan	-2.80	-3.14	-1.03
Feb	-17.54	-9.12	-21.47
Mar	-33.77	-31.05	-37.72
Apr	-6.26	-5.12	-10.40
May	-12.28	-13.35	-20.05
Jun	18.85	16.04	18.19
Jul	-27.08	-18.02	-3.10
Aug	-5.33	10.22	37.32
Sep	16.07	18.04	35.78
Oct	12.54	9.24	12.94
Nov	24.21	24.00	23.38
Dec	5.87	4.75	7.15

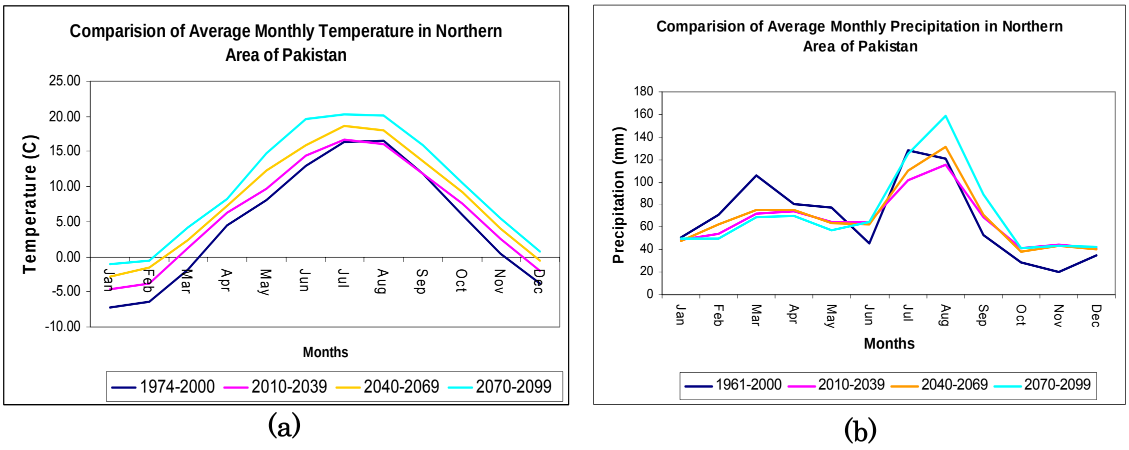


Figure 51: Statistically downscaled projected (a) Temperature (°C) and (b) Precipitation (mm) in Northern Region of Pakistan and baseline values.

3.4. Dissemination of Research Results

Dissemination of the main findings of research to different stakeholders, particularly the national planners and policy makers, was an important component of this project. A number of activities to this effect were carried out by the participating organisations. These included, inter alia, publication of research papers in international and national journals; contributions to international and national conferences; distribution of the proceedings of CAPaBLE Workshops to relevant organisations; presentations by senior team members in various roundtables and discussion groups on the subject organised by government departments, NGOs, educational and scientific institutions and electronic mass communication media; and presentations to distinguished national and international dignitaries visiting the participating organisations. One particularly important dissemination activity worth specific mention, is the organisation of two one-day briefing seminars, one in Nepal and the other in Pakistan, chaired by the respective Heads of Planning Commissions, in Kathmandu and Islamabad respectively in August 2007, the last month the project tenure. These seminars were organised to disseminate the final findings of the project to a large number of senior and middle level national planners and policymakers, government and non-governmental officials, academicians and scientists. The participants of both the seminars appreciated not only the good work of national importance carried out under the project but also the useful role being played by APN in building the much needed climate change research capacity of developing countries of the region.

4. CONCLUSIONS

The present project aimed at:

- Enhancing Climate Change (CC)-related research capacity of the beneficiary countries (Bangladesh, Nepal and Pakistan) in areas of Regional Climate Modelling (RCM), Watershed Simulation Modelling (WSM) and Crop Simulation Modelling (CSM);

- Making use of the enhanced capacity to (i) formulate country specific plausible CC scenarios, (ii) assess the corresponding impacts on water resources and agricultural production, and (iii) identify appropriate adaptation measures to cope with the adverse impacts;

- Disseminating the research results to national planners and policy makers; and

- Providing useful inputs to IPCC Assessment Reports.

The above objectives were fulfilled in the following manner:

A. Capacity Building

For capacity building, 4 Regional Capacity Building Workshops were held, one each on RCM, WSM and CSM and one on Climate Scenario Development for Impact Analysis. (For details see Appendix I in Technical Report): The total No. of Participants in these Workshops were 99 (Pakistan: 49, Nepal: 29, Bangladesh: 21) In addition, 2 Regional Workshops were held for the discussion and harmonization of research results. These were attended by 62 participants (Pakistan: 49, Nepal: 13);

As a result of the above capacity building activities, supplemented by the effort of the participating countries themselves, the following Simulation Models were acquired, implemented, validated, and calibrated by various organizations in the project countries and are now being used by them (the origins of the models and the user countries are shown in parentheses; BD = Bangladesh; Nep= Nepal; Pak = Pakistan):

a) Regional Climate Models (RCMs)
   - RegCM3 (Int. Centre for Theo. Physics, ICTP, Italy); (Users: Pak, Nep, BD)
   - PRECIS (Hadley Centre, British Met Office, UK); (Users: Pak, Nep)
   - MM5 and WRF (National Center for Atmospheric Research, NCAR, USA); (User: Pak)

b) Watershed Simulation Models (WSMs)
   - DHSVM (University of Washington, USA); (Users: Pak, Nep, BD)
   - UBC (University of British Columbia, Canada); (User: Pak)
   - HEC-HMS (US Corps of Army Engineers, USA); (Users: Pak, Nep, BD)
   - BTOPMC (University of Yamanashi, Japan); (User: Nep)
   - HFAM (Hydrocomp Inc., USA); (User: Nep)
   - WatBal (D.N. Yates, Int. J. Water Res. Dev., Vol. 12, p. 121, 1996); (User: Nep)

c) Crop Simulation Models (CSMs)
   - DSSAT (University of Georgia, Griffin, USA); (Users: Pak, Nep, BD)
     DSSAT comprises the following component models:
     - CERES family of models for cereals
     - CROPGRO family of models for grain legumes
     - CROPSIM family of models for root crops

- o Individual models for other crops (Tomato, Sunflower, Sugarcane, Pasture)

B. Research

Based on the above capacity building activities, the following research effort was undertaken:

i. Asessment of the CC trends in various parts of Bangladesh, Nepal and Pakistan over the last 3 to 5 decades by analysing the available meteorological data;

ii. Testing, selection, validation and calibration of various Simulation Models: RCMs, WSMs and CSMs for CC research;

iii. Formulation of CC projections to the year 2100 for Bangladesh, Nepal and Pakistan, each, and for large sub-regions of Pakistan, based on the coarse resolution (about 300 km X 300 km) outputs of an ensemble of Global Circulation Models (GCMs) corresponding to selected IPCC scenarios;

iv. Development of high resolution (50 km X 50 km) CC scenarios for each of the participating countries by dynamic downscaling of the available GCM outputs for selected IPCC scenarios using the Regional Climate Models RegCM3 and PRECIS;

v. Assessment of the impacts of projected CC on the yields of wheat, rice and maize crops in different agro-climatic zones of the participating countries;

vi. Assessment of the impacts of CC on the annual and seasonal flows of the main rivers of each participating country; and

vii. Identification and evaluation of the appropriate adaptation measures and coping mechanisms to counter the negative impacts of CC in the Agriculture and water sectors.

Several of these research activities are on-going and will continue over the foreseeable future. The work has already resulted in the publication of 2 monographs, 4 research papers in international journals/books, 3 papers in national journals, 8 workshop proceedings and 21 draft reports, while a few more are in the pipeline. Besides, 71 research papers were presented at various international conferences and 21 at national level conferences. (For more information, please see Appendices II-IV.) Some salient research results are presented below:

C. Salient Research Results

a. Past Climate Changes

- Pakistan
  Analysis of the 50-years (1951-2000) climate data for precipitation and temperature revealed that:

i. The mean annual temperature increased in most parts of Pakistan except in sub-montane region, western highlands and lower Indus plains where it decreased. All the zones show an increasing trend in temperature for the pre-monsoon summer months (April-May).

ii. All the zones, except the Balochistan Plateau, which is an arid and hyper-arid region, show a decreasing trend for the monsoon period (June-September).

iii. Balochistan plateau is getting warmer in all the seasons.

iv. The mean annual precipitation has generally been increasing except in coastal areas. The monsoon precipitation shows essentially the same trend. The winter rains show a mixed trend with decreasing trend appearing in Western Highlands and a part of Balochistan Province. The Greater Himalayas show a trend of increasing precipitation during the monsoon period (JJAS) and that of slightly decreasing trend in winter months (DJFM).

- Nepal

Climate changes based on the data from 1975 to 2005 were identified as:

i. The mean temperature of the country is increasing steadily at the linear rate of 0.04 °C/year. However, between 1975 and 2005 the mean annual temperature increased by 1.7 °C.

ii. The linear trend of monsoon rainfall shows slight positive tendency amounting to about 2.08 mm/year with large inter-annual variation.

b. GCM based Coarse Resolution Climate Change Scenarios

The area averaged values of GCM ensemble based projected changes in temperature and precipitation, on annual basis as well as for summer (JJAS) and winter (DJFM), over the regions covered by Pakistan, Nepal and Bangladesh under A2 and A!B scenario show that:

i. The rises in temperature on annual as well as on seasonal basis in Pakistan and Nepal are comparable whereas those in Bangladesh are relatively lower.

ii. Temperature increase in all the three countries (Pakistan, Nepal & Bangladesh) for time slices 2020s, 2050s and 2080s is higher in winter than in summer.

iii. There are clear indications that in all the three countries, precipitation will increase in summer and decrease in winter (only a slight decrease in the case of Pakistan). On annual basis precipitation will increase in Bangladesh but will have no significant change in Nepal and Pakistan.

c. PRECIS based Fine Resolution Climate Change Scenarios for 2080s

- Pakistan.

The spatial patterns of changes in temperature and precipitations over Pakistan by 2080s using the RCM: PRECIS on annual and seasonal basis show:

i. The rise in annual mean temperature will be 5.5 °C over Central Punjab, 3.5 to 4 °C over coastal areas and 4.5 to 5°C over rest of the country.

ii. The rise of temperature in Pakistan in winter will be generally more than that in summer.

iii. Over northern areas of Pakistan, the increase in temperature will be up to 6 °C in summer whereas in winter, the rise will be in the range of 4 to 5°C.

iv. Winter precipitation will increase in northern areas of Pakistan but the summer precipitation will decrease.

- Nepal

i. The Northern parts of the country in 2080s, show higher increase in temperature than the middle and southern parts. The middle part has the lowest temperature increase.

ii. Precipitation changes are higher in the eastern and southern parts of Nepal as compared to its northern parts.

- Bangladesh.

i. Most of central and western parts of Bangladesh will have temperature change in the range of 4 to 4.5°C, while the coastal regions in the south and southeast will have temperature change ranging from 2.5 to 4°C.

ii. Precipitation in the eastern half of the country will increase in the range of 40 to 70 %, while the western half of the country will have an increase of only 15 to 40 %.

d. RegCM3 based Fine Resolution Climate Change Scenarios

Because of the bugs found in RegCM3 code during the course of this work, the corresponding model simulations are being repeated now and, therefore, the results obtained in the previous simulation runs are not being presented here.

- ***Impacts on Agriculture***

1. (i)Wheat is the staple food crop of Pakistan and is grown throughout the country in four agro-climatic zones; viz. Northern mountainous, Sub-mountainous, Semi-arid plains and Arid plains. The CERES-Wheat model based simulation studies carried out in Pakistan show that the Growing Season Length (GSL) of wheat will decrease with increasing average temperature in all the agro-climatic zones, the magnitude of decrease being the highest in the Northern Mountainous region. The yield in this region will increase with rise in temperature until about 4°C above the baseline, when the GSL will approach the optimum value of 190-200 days. The prevalent GSL of 246 days in the Northern region is much higher than the optimum. The low temperature is a stress in this area as wheat does not go to maturity; it is usually fed to animals as fodder. Given the meager 2% contribution of this region to the overall national production, its increase in yield will not have any significant impact on the national wheat productivity in Pakistan.

   (ii) The yield projections, using CERES-Wheat model under IPCC-SRES A2 and B2 Scenarios revealed that national wheat production in Pakistan is likely to decrease by 5-6% by 2080s.

2. (i) Rice is another important cereal crop of Pakistan. It has two main types: (a) fine-grain aromatic, Basmati rice grown mostly in the semi-arid region of Punjab, Pakistan and (b) IRRI-type coarse-grain non-aromatic rice which is grown mostly in arid-region of Sindh. The CERES-Rice model showed that GSL of Basmati rice will decrease with rise in temperature. The yield of Basmati rice will also follow the decreasing trend with rising temperature. The rice crop, in general, appears to be more sensitive to rise in temperature than the wheat crop.

   (ii) The yield projections of Basmati rice, using CERES-Rice model under IPCC-SRES A2 and B2 Scenarios revealed that the national Basmati rice production in Pakistan is likely to decrease by 15-18% by 2080s.

3. In Nepal, the model-based studies revealed that the rise in temperature upto 4°C as well as an increase of CO_2 concentration by 250 ppm will have positive impacts

on major crops in all the ecozones. The rise in temperature of 2°C will, however, exert negative effect on maize in the Mountain zone. The Mountain environment will be more favorable than the tropical flat lands for major crops. Tropical crops are therefore likely to move upwards due to increase in temperature due to climate change.

4. Some adaptive measures have been identified in Pakistan with the help of CERES-models e.g. (i) advancing the sowing dates to escape sensitive reproductive stages from scorching temperatures, and (ii) the efficient use of irrigation water by changing the number of irrigations to coincide with the water-sensitive growth stages keeping the amount of water the same.

- ***Impacts on Water Resources***

Five different watershed models were used (2 in Pakistan, 4 in Nepal) to simulate the flows from different river basins. The main findings are:

i. In Pakistan, the semi-distributed UBC watershed model was applied to simulate the flow from the watersheds of Indus River Basin, involving different hydrological regimes (monsoon rains only; glacier melt and snowmelt; rain, glacier melt and snowmelt). The model was found to reproduce the flows to the extent of 80-90% in the case of rivers fed mainly by glacier melt and snowmelt, with relatively minor contribution from rainfall. The UBC watershed model could therefore be strong candidate for the climate change impact assessment studies on Indus River flows.

ii. Due to its very demanding data input requirements, DHSVM could be applied only to a small basin (~1000 sq. km) fed by rainfall only. The results were encouraging. Being a distributed model, DHSVM could be of great value for climate change impact studies on river flows in a complex terrain like the Indus Basin. As such, this model needs to be further explored.

iii. The preliminary results obtained with DHSVM were not encouraging in the work done in Nepal. However, further work is necessary before a decision on the usefulness of this model for the Nepalese watershed environment could be made.

iv. The Nepalese team is also experimenting with three other watershed models (BTOPMC, HFAM, WatBal) in order to check their suitability for climate change studies in Nepal. As yet, the results are not conclusive.

e. Briefing of National Planners

Two one-day National Seminars were Held, one in Nepal and one in Pakistan in last month of the project tenuer to brief the senior and middle level national planners and policymakers about the research findings of this projectfor. These seminars were chaired by the respective heads of Planning Commissions in the two countries. The total No. of Participants was 352 (Pakistan: 240, Nepal: 112) (For details see Appendix I in Technical Report):

5. FUTURE DIRECTIONS

The participating institutions and scientists of this project may now build upon the solid foundation laid through the project in the following manner:

i. Finalise the research work already done and that in progress and publish it in international journals of repute as soon as possible; also finalise detailed technical reports, and publish and widely disseminate them to help other national institutions and scientists to benefit from this effort;

ii. Develop capability to make necessary alterations and modifications in the scientific logic and structure of the available simulation models so that they become more responsive to the local or regional conditions;

iii. Develop capability to take advantage of the recent advancements in modelling techniques which could lead to reliable predictions at inter-decadal, inter-annual and seasonal levels, these time scales being of particular interest to most stakeholders;

iv. Explore the possibility of using additional RCMs as well as additional GCMs in combination with RegCM3 and PRECIS in order to increase the reliability of the climate change scenarios;

v. A major problem in the validation of RCMs, particularly in the mountainous areas of the South Asia region, is the lack of sufficiently dense observational network. It should be emphasised on the relevant organizations in Pakistan and Nepal to expand the networks adequately;

vi. As a typical RCM based simulation experiment over the South Asian domain covering just one 30-year time slot takes 3-4 months on a Pentium-IV computer, effort should be made to increase computing speed by developing clusters with several nodes in order to cut down the experiment time to manageable limits;

vii. The studies on impact of climate change need to be extended to other important crops, e.g. cotton, potato, etc. and should make use of two or more crop simulation models for the same crop in each region in order to reduce model based uncertainties;

viii. Water being the main driver of agricultural productivity, its availability needs to be assured for ensuring food security. Therefore, for irrigated areas, watershed and water management models need to be used in conjunction with crop simulation models to optimize the use of available water under changing climatic conditions and increasing demand of agricultural outputs;

ix. State-of-the-art capability based on advanced remote sensing & GIS techniques should be developed to measure and monitor the snow cover and temporal changes in the major glaciers of Hindukush-Karakoram-Himalaya (HKH) region feeding the region's important rivers. Also, based on this, develop the capacity to make seasonal forecast of river flows;

x. Extend the scope of research to address some other important impacts of climate change e.g. those on glaciers, human health, deforestation, land degradation and desertification, loss of biodiversity, intrusion of sea water in deltaic regions etc.;

xi. Identify and assess appropriate measures to counter the adverse impacts of climate change in various socio-economic sectors; and

xii. Undertake economic valuation of climate change impacts in terms of economics and socioeconomic consequences by coupling the biophysical models with the socioeconomic models.

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APPENDICES

Appendix I: Regional Workshops and National Seminars

Agenda/Programme (including title, date and venue) and Participants list (comprising contact details of participants (including organisation, address, phone number, fax number, email address etc.) are provided in the CD of this Report

a) Regional Capacity Building Workshops:

1. Workshop on Regional Climate Modelling, February 16 - 27, 2004, Islamabad, Pakistan: No. of Participants: 26 (Pakistan: 14, Nepal: 6, Bangladesh: 6);
   No. of Resource Persons: 5 (ICTP: 4, Pakistan: 1)

2. Workshop on Crop simulation Modelling, June 28 – July 9, 2004, Chiang Mai, Thailand: No. of Participants: 21 (Pakistan: 9, Nepal: 6, Bangladesh: 6);
   No. of Resource Persons: 2 (USA: 1, Thailand: 1)

3. Workshop on Watershed Simulation Modelling, March 7 – 18, 2005, Islamabad, Pakistan: No. of Participants: 28 (Pakistan: 18, Nepal: 5, Bangladesh: 5);
   No. of Resource Persons: 4 (Australia: 1, Pakistan: 3)

4. Workshop on Climate Change Scenarios for South Asia, August 15–19, 2005, Kathmandu Nepal: No. of Participants: 24 (Pakistan: 8, Nepal: 12, Bangladesh: 4);
   No. of Resource Persons: 3 (ICTP: 2, China: 1)

b) Regional Workshops for Discussion and Harmonization of Research Results

1. Workshop on Comprehensive Climate Change Research Results, June 19 - 23, 2007, Kathmandu, Nepal: No. of Participants: 24 (Pakistan: 14, Nepal: 10);
   No. of Resource Persons: 1 (ICTP: 1)

2. Workshop for Harmonisation of Climate Change Research Results, August 21 - 25, 2007, Islamabad, Pakistan: No. of Participants: 38 (Pakistan: 35, Nepal: 3)

c) National Seminars for Briefing National Planners and Policymakers

1. Interaction Programme on Role of Climate Change in the Development Process, 15 August 2007, Kathmandu, Nepal: No. of Participants: 112

2. Briefing Seminar on Climate Change Research Results for National Planners and Policy Makers, 28 August, 2007, Islamabad, Pakistan: No. of Participants: 240

Appendix II: Publications

a) Monographs (in collaboration with COMSTECH): (Not available on CD)

1. Climate Change: Global and OIC Perspective, 2004
2. Energy Strategies for the OIC Member States, 2004

b) Peer Reviewed Journal and Book Publications:

(Full texts are given in the CD)

INTERNATIONAL (PAKISTAN)

i. "Prospects for Wheat Production under Changing Climate in Mountain Areas of Pakistan – An Econometric Analysis", Hussain, S. S. and M. Mudasser, Science Direct, Agricultural Systems, Elsevier Applied Science, UK, Vol.94 (2007), pp. 494-501.

ii. "Effect of Remote Forcings on Winter Precipitation of Central Southwest Asia Part 1: Observations", Faisal S. Syed, F. Giorgi, J. Pal and M. P. King, Theoretical and Applied Climatology, Springer, Germany, 2006, Vol. 86, Pp 147-160.

iii. The ICTP RegCM3 and RegCNET: Regional Climate Modeling for the Developing World", Jeremy S. Pal, F. Giorgi, M. Ashfaq and Faisal S. Syed, Bulletin of the American Meteorological Society, **Accepted** Nov. 2006.

iv. "Droughts in Pakistan: Causes, Impacts and Remedial Measures', Pervaiz Amir and M. Munir Sheikh, **a Chapter in the Book**: 'Climate and water Resources in South Asia: Vulnerability and Adaptation' edited by Amir Muhammed, M. Monirul Qader Mirza and Bonnie A Stewart, Asianics Agro Dev. International, Islamabad, Pakistan, 2006.

v. "Effect of Remote Forcings on Winter Precipitation of Central Southwest Asia Part 2: Modeling", Faisal S. Syed, F. Giorgi, J. Pal and M. P. King, **submitted** to Climate Dynamics.

vi. "Greenhouse Gas Emissions from Aro-Ecosystems and Their Contribution to Environmental Change in Indus Basin of Pakistan", M. Mohsin Iqbal and M. Arif Goheer, **submitted** to Advances in Atmospheric Sciences, China.

vii. "Remote Sensing and GIS Based Measurements of Temporal Changes in Lateral Dimensions of Biafo Glacier in Central Karakoram, Himalaya, Northern Pakistan", Muhammad Haroon Siddiqui, Ghazanfar Ali, Arshad M. Khan, **submitted** to Hydrological Processes, 2007.

INTERNATIONAL (BANGLADESH)

i. "Calibration of RegCM3 simulated meteorological parameters in Bangladesh: Part I - preliminary result for rainfall", Md. Mizanur Rahman, Md. Nazrul Islam, Ahsan Uddin Ahmed and Romee Afroz. **Submitted** to Sri Lanka Journal of Physics (Revised).

ii. "Calibration of RegCM3 simulated meteorological parameters in Bangladesh: Part II - preliminary result for temperature, Md. Mizanur Rahman, Md. Nazrul Islam, Ahsan Uddin Ahmed and Romee Afroz. **Submitted** to Sri Lanka Journal of Physics (Revised).

NATIONAL (PAKISTAN)

i. "Variation in Fog Intensity/ Duration and EI Nino", Faisal S. Syed and Asma Younas, Pakistan Journal of Meteorology, Pakistan Meteorological Department, Islamabad, Vol.1 Issue:1, pp. 49, Jan-March 2004.

ii. "Climate Variability in Mountain Areas of Pakistan - Implications for Water Resources and Agriculture", Hussain, S. S., M. Muddasser, M. Munir Sheikh and M. Naeem, Journal of Meteorology, Pakistan Meteorological Department, Jan. 2005.

iii. "Simulations of 1992 Flood in River Jhelum using High Resolution Regional Climate Model, PRECIS to study the underlying Physical Processes involved in the Extreme Precipitation Event", Sajjad Saeed, M. Munir Sheikh, Syed Faisal Saeed, Pakistan Journal of Meteorology, Vol. 03, Issue 06, December 2006.

iv. "Simulations of Super Cyclonic Storm in Bay of Bengal by using a Nested Regional Climate Model PRECIS: Domain Size Experiments", Sajjad Saeed, M. Munir Sheikh, G. Rasul, **Submitted** to Pakistan Journal of Geography, 2007

c) Workshop/ Seminar Proceedings:

i-vii. These 7 Proceedings of Regional Workshops/ Seminars are listed at Serial Nos. 1 - 6 and 8 under the head "Regional Workshops and National Seminars Held" in the Section on "Work undertaken". *(Please see the attached CD for full texts of these Proceedings.)*

viii. Proceeding of Capacity Building Workshop on Global Change Research, June 8 - 10, 2004, Islamabad, Pakistan (in collaboration with Agro- Dev. International).

ix. Proceeding of National Workshop on Global Change Perspective in Pakistan: Challenges, Impacts, Opportunities & Prospects, April 28 - 30, 2005, Islamabad, Pakistan (in collaboration with Agro- Dev. International)

x. Proceeding of International Conference on Global Change, Nov. 13 - 17, 2006, Islamabad, Pakistan (in collaboration with National Centre for Physics), (under process).

Appendix III: Contributions to Conferences
(Please see the accompanying CD for full texts and /or Power Point presentations.)

a. Contributions to Conferences (other than those to the Workshops/ Seminars of the present project):

INTERNATIONAL CONFERENCES (PAKISTAN)

1. Muhammad Munir Sheikh, Past and Projected Climate Changes in Pakistan, Presented at APN Workshop: Water Resources in South Asia: An Assessment of Climate Change-associated Vulnerabilities and Coping Mechanisms, Kathmandu, Nepal, 15 - 19 Dec., 2003.

2. Syed Sajidin Hussain, Impact of Climate Change on Agriculture in Mountain Areas of pakistan, Presented at International Workshop on: "Adaptation to Climate Change in Mountain Ecosystems: Bridging Research and Policy", Kathmandu, Nepal, 3-5 March 2004.

3. Syed Faisal Saeed, Simulation of Winter Precipitation over South Asia, Presented at Second Workshop on the Theory & Use of Regional Climate Models, Trieste, Italy, May 31 - June 9, 2004.

4. M. Munir Sheikh and Naeem Manzoor, Climate Change in Mountain Regions of Pakistan, Presented at APN Stakeholders meeting, Islamabad, Pakistan, 7 August, 2004.

5. Syed sajidin Hussain, Climate Variability in Mountain Regions of Pakistan-Implications for Water and Agriculture, Presented at International Conference on: "Sustainability of Communities in Remote Environments: Hindukush, Pakistan", Baragali, Galiat, Pakistan, 06-08 September, 2004.

6. Syed Sajidin Hussain, Pakistan Site Selection for Case Study, Presented at International GECAFS Workshop, Dhaka, Bangladesh, 14-16 March, 2005.

7. Arshad M. Khan, Development of Research on the Evaluation of Vulnerability under the APN CAPaBLE Programme and Future Research Priority Areas, Presented at APN Science Symposium "Environmental Vulnerability in the Asia-Pacific Region - Assessments and Countermeasures", Kobe, Japan, 13 April 2005.

8. M. Munir Sheikh and Naeem Manzoor, Climate Variability and Change in the Mountainous North of Pakistan, Presented at International Karakoram Conference, Islamabad, Pakistan, 25 - 27 April, 2005.

9. Fahad Saeed et al., Study of the Hydrological Impact of Global Warming in Hindukush- Karakurum-Himalayan Region Using a Distributed Hydrological Model, Presented at International Karakurum Conference, Islamabad, Pakistan, 25 - 27 April 2005.

10. Humaira Sultana, Agricultural Potential in Karakoram Region under Changing Climate, Presented at International Karakurum Conference, Islamabad, Pakistan, 25 - 27 April 2005.

11. Syed Faisal Saeed, Imran Nadeem and Sajjad Saeed, Climate Simulation Evaluation and Transferability of Different Convective Schemes in RegCM3 Over South Asia Region, Presented at the Scientific Assembly of the International Association of Meteorology and Atmospheric Sciences, Beijing, China, 2 - 11 August 2005.

12. Naeem Manzoor, Muhammad Munir Sheikh, Syed Faisal Saeed , ENSO & NAO Influences over the Weather of Pakistan, Poster presentation at Scientific Assembly of the International Association of Meteorology and Atmospheric Sciences (IAMAS 2005), Beijing, China, 2-11 August 2005.

13. S. Shoaib Raza, Abdul Basit, Munir Sheikh, Niaz Ahmed, Simulation of Weather Events During Monsoon Season over South Asia Using RegCM3, Presented at the Scientific Assembly of IAMAS 2005, Beijing, China, 2 - 11 August 2005.

14. Fahad Saeed, Imtiaz Ahmed, Shahzad Jehangir, Impact Assessment of Land Cover Changes in Upper Indus Basin Using Distributed Hydrological Model: A Case Study of Siran Watershed, Poster Presented at International Workshop on Land Surface Models and their Applications, Zhuhai, China, 15 – 18 November 2005.

15. M. Mudasser, Impact of Change in Climate and Water Resources on Wheat Production in Arid and Semi Arid Area of Punjab, Pakistan, Poster Presented at International Workshop on: "Land Surface Models and their Applications", Zhuhai, China, 15-18 Nov. 2005.

16. M. Munir Sheikh and Naeem Manzoor, Climate Change – A Global Issue, Presented at International Workshop on Impact of Weather and Climate on Society Affairs, Department of Meteorology, CIIT, Islamabad, Pakistan, 24 - 26 Nov. 2005.

17. Kashif Majeed Salik, Site Characterization GUJRAT-Pakistan, Presented at Plenary meeting of GECAFS Project, Kathmandu, Nepal, 12-15 Dec. 2005.

18. Nazim ali, Food System in Pakistan, Presented at Plenary meeting of GECAFS Project, Kathmandu, Nepal, 12-15 Dec. 2005.

19. Sajida A. Noor, Yasin.M, Ali. N, M. Arif Goheer, Genetic Interrelationship and Their Implications for Yield Improvement in Linseed, Presented at International Frontis Workshop on "Gene-Plant Crop Relations- Scale and Complexity in Plant Systems Research", WICC, Wageningen, Netherlands, 23 - 26 April 2006.

20. M. Munir Sheikh, Mountainous North of Pakistan in the Context of Past and Projected Climate Changes, Presented at Karakoram-Kashmir International Conference, Islamabad, Pakistan, 31 May 2006.

21. Fahad Saeed, Impact Assessment of Land Cover Changes in Upper Indus Basin Presented at Third ICTP Workshop on the Theory and Use of Regional Climate Models, Trieste, Italy 1 – 9 June 2006.

22. Nazim Ali, Climate Change and Water Supply Security in Karachi, Presented at International Workshop under Global Water System Project (GWSP-Asia), Guangzhou, China, 8 - 12 June 2006.

23. Mohsin Iqbal, Field activities in Gujrat District, Pakistan-GECAFS IGP Site 1, Presented at GECAFS IGP CPW&F and APN Launching Workshop, Kathmandu, Nepal, 27- 30 June 2006.

24. Nazim Ali, Vulnerability Assessment of Food System, Presented at GECAFS IGP CPW&F and APN Launching Workshop, Kathmandu, Nepal, 27- 30 June 2006.

25. Arif Goheer, Climate Change and Food Production in Pakistan, Presented at GECAFS IGP CPW&F and APN Launching Workshop, Kathmandu, Nepal, 27- 30 June 2006.

26. Kashif Majeed, Mapping to GECAFS Food Matrix-Gujrat Pakistan (IGP, Site 1), Survey Results, Presented at GECAFS IGP CPW&F and APN Launching Workshop, Kathmandu, Nepal, 27- 30 June 2006.

27. M. Arif Goheer et al., Rice production in the semiarid irrigated areas of central Punjab, Pakistan under changing climatic scenarios: impacts and adaptations, Presented at International symposium on sustainable crop improvement and integrated management,University of Agriculture, Faisalabad, Pakistan, 14 -16 September 2006.

28. Humaira Sultana, Vulnerability of Wheat Production in Different Climatic Zones of Pakistan under Climate Change Scenarios using CSM-CERES-Wheat Model, Poster Presented at 2nd International Young Scientists' Conference, Beijing, China, 3-8 Nov., 2006.

29. Siraj ul Islam, Future Change in the Frequency of Warm and Cold Spells Durations over Pakistan Simulated by the PRECIS Regional Climate Model, Poster Presented at 2nd Young Scientists' Global Change Conference (YSC), Beijing, China, 5 - 8, November 2006.

30. Siraj ul Islam, Future Change in the Frequency of Warm and Cold Spells Durations over Pakistan Simulated by the PRECIS Regional Climate Model, Poster Presented at Earth System Science Partnership's (ESSP) Open Science Conference (OSC) on Global Environmental Change: Regional Challenges, Beijing, China, 09-12 November, 2006.

31. Sajida Ali, Optimizing the use of water through direct seeding of rice - CERES- Rice model Studies in the Semi -Arid Irrigated plains of Punjab, Presented at International Forum on Water and Food, Vientiane, Lao PDR, 12 - 17 November 2006.

32. M. Munir Sheikh et al., Climate Extreme Trends in South Asia, Presented at International Conference on Global Change (Joint AS-ICTP and NCP Activity), Islamabad, Pakistan, 13 - 17 November 2006.

33. S. Faisal Saeed et al., Climate Change Studies over South Asia Region Using Regional Climate Model RegCM3 (Preliminary Results), Presented at International Conference on Global Change (Joint AS-ICTP and NCP Activity), Islamabad, Pakistan, 13 - 17 November 2006.

34. Siraj-ul-Islam and Nadia Rehman, Assessment of Future Change in Temperature and Precipitation over Pakistan (Simulated by PRECIS RCM for A2 Scenario), Presented at International Conference on Global Change (Joint AS-ICTP and NCP Activity), Islamabad, Pakistan, 13 - 17 November 2006.

35. Nauman Khurshid, Investigation of wind power potential along coastline of Pakistan using Mesoscale Model, Presented at International Conference on Global Change (Joint AS-ICTP and NCP Activity), Islamabad, Pakistan, 13 - 17 November 2006.

36. Mohsin Iqbal, Monsoon Asia Mountain Zone of Pakistan-National Perspective, Presented at MAIRS Mountain Workshop, Beijing, China, 14 - 17 Nov., 2006.

37. Rehan Anis, Comparison of Different Interpolation Methods for Temperature Mapping in Pakistan, Presented at 2nd International Conference on Water Resources and Arid Environment, Riyadh, Saudi Arabia, 26 - 29 November 2006.

38. Imran Shahid, Effect of Transboundary Air Pollution on Air Quality of Northeastern Region of Pakistan, Poster Presented at Better Air Quality Workshop, Yogyakarta, Indonesia, 13 - 15 December 2006.

39. M. Mohsin Iqbal, Impact of Global Environmental Change on Water Resources and Food System in Indus Basin of Pakistan, Presented at APN CAPaBLE Workshop on Food and Developing Decision Support System, Kathmandu, Nepal, February 27- March 02, 2007.

40. Nazim Ali, Food Security, Policy Change? Why? What? Where? And How?, Presented at Project Meeting of APN Food System, Kathmandu, Nepal, 01-02 March 2007.

41. M. Mohsin Iqbal, Climate Change Impact Assessment on Rice Production in Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

42. M. Mohsin Iqbal, Adaptation Strategies to Cope with Negative Imapcts of Climate change on Agriculture in Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

43. M. Munir Sheikh, et al, Drought and Desertification Trends in Pakistan: Past and Future, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

44. M. Munir Sheikh, et al, Past Climate Changes in Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

45. Ghazanfar Ali, Climate Change: Implications and Adaptation for Water Resources in Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

46. Ghazanfar Ali, River Flow Related Models in use at GCISC, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

47. Siraj-ul-Islam, et al, Climate Change Scenarios for Pakistan and some South Asian Countries Based on Six Different GCMs and Their Ensemble, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

48. Siraj-ul-Islam, et al, Climate Change Scenarios for Pakistan, Nepal and Bangladesh for SRES A2 and A1B Scenarios, Using Outputs of 17 GCMs used in from IPCC AR4, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

49. Siraj-ul-Islam, et al, Climate Change Scenario Over South Asia Region Simulated by PRECIS RCM, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

50. Siraj-ul-Islam, et al, Validation of Regional Climate Model PRECIS Over South Asia, Presnted at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

51. Naeem Manzoor, et al, Forcing Factors and Their Impacts on the Weather of Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

52. Muhammad Adnan, et al, Assessment of Future Change in Temperature Extreme Indices using Regional Climate Model PRECIS Over Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

53. Muhammad Adnan, (Part of Presentation) Drought and Desertification Trends in Pakistan: Past and Future, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

54. Faisal S. Syed, et al, Climate Change Studies Over South Asia Region Using Regional Climate Model RegCM3, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

55. Faisal S. Syed, et al, Effect of Bugs in RegCM3 on the Simulation of Climate Over South Asia, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

56. Faisal S. Syed, et al, Quantification of Uncertainities in the Regional Climate Projections, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

57. Kashif Majeed Salik, Climate Change Impact Assessment on Wheat Production in Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

58. Sajida Ali, et al, Optimizing the use of water through direct seeding of rice - CERES-Rice model Studies in the Semi -Arid Irrigated plains of Punjab, Paper Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

59. Sajida Ali, Evaluation of CERES-Rice & CERES-Wheat Model for Climate Change Studies in Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

60. Muhammad Haroon Siddiqui, Monitoring of Biafo Glacier of Karakoram Using Remote Sensing and Geographical Information Systems (GIS) Techniques, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

61. Rizwan Aslam, et al, Comparison of Different Interpolation Methods for Temperature Mapping in Pakistan, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

62. Rizwan Aslam, et al, Development of Climate Change Scenarios for Pakistan Corresponding to Selected GCM Outputs, Using Statistical Downscaling, Presented at South Asia APN CAPaBLE Regional Workshop on Comprehensive Research Results of Climate Change and Its Impacts on South Asia, Kathmandu, Nepal, 19-23 June, 2007.

63. S. Shoaib Raza, APN CAPaBLE Project on Enhancement of National Capacities for Climate Change Research in Bangladesh, Nepal and Pakistan: Objectives, Activities and Achievements, APN CAPaBLE National Seminar on Climate Change Research Results, Kathmandu, Nepal, 06 August, 2007.

64. Muhammad Haroon Siddiqui, Ghazanfar Ali and Arshad M. Khan, Remote Sensing and GIS Based Measurements of Temporal Changes in Lateral Dimensions of Biafo Glacier in Central Karakoram, Himalaya, Northern Pakistan, Presented at Glaciers in Watershed and Global Hydrology, Obergurgl, Austria, 27-31 August, 2007.

INTERNATIONAL CONFERENCES (BANGLADESH)

1. Islam M. Nazrul, Md. Mizanur Rahman, Ahsan Uddin Ahmed and Romee Afroz, 2005: Simulation of rainfall and temperature using RegCM over Bangladesh, Scientific Assembly of the Int. Asso. of Meteo. and Atmos. Sci. (IAMASS 2005), C2-Regional Climate Studies, Beijing, China, 2 - 11 August 2005.

2. Romee Afroz, Islam M. Nazrul, Md. Mizanur Rahman, Ahsan Uddin Ahmed, 2005: Radiation/Heat Budget of the Earth's surface over South Asian Region using RegCM3 Model, Scientific Assembly of the Int. Asso. of Meteo. and Atmos. Sci. (IAMASS 2005), C2-Regional Climate Studies, Beijing, China, 2 - 11 August 2005.

3. M. Rafiuddin, Islam M. Nazrul and A. U. Ahmed, 2006: RegCM3 in simulating cyclone developed over the Bay of Bengal. Presented at Third ICTP Workshop on the Theory and Use of Regional Climate Models, ICTP, Trieste, Italy, 29 May - 9 June 2006.

4. M. Rafiuddin, Islam M. Nazrul and A. U. Ahmed, 2006: Application of Regional Climate Models in Meteorological Aspects in Bangladesh. Presented at Third ICTP Workshop on the Theory and Use of Regional Climate Models, ICTP, Trieste, Italy, 29 May - 9 June 2006.

INTERNATIONAL CONFERENCES (NEPAL)

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Appendix IV: Draft Technical Reports

(*These Draft Reports are now going through a review process. Please see the attached CD for their full texts.*)

PAKISTAN

DR-1: Climate Profile and Past Climate Changes in Pakistan.
DR-2: Climate Change Scenarios for Pakistan and Some South Asian Countries Based on Six Different GCMs and their Ensemble.
DR-3: Climate Change Scenarios for Pakistan, Nepal and Bangladesh for SRES A2 and A1B Scenarios using outputs of IPCC AR4 17 GCMs (Interim Report)
DR-4: Validation of Regional Climate Model PRECIS over South Asia.
DR-5: Assessment of Future Change in Temperature Extreme Indices using Regional Climate Model PRECIS Over Pakistan
DR-6: Climate Change Scenarios Over South Asia Region Simulated by PRECIS RCM (Interim Report)
DR-7: Validation of Regional Climate Model RegCM3 over South Asia.
DR-8: Climate Change Scenarios for 2050s & 2080s over South Asia using Regional Climate Model RegCM3 (Interim Report)
DR-9: Development of Climate Change Scenarios for Specific Sites Corresponding to Selected GCM Outputs, using Statistical Downscaling Technique.
DR-10: Comparison of Different Interpolation Methods for Temperature Mapping in Pakistan.
DR-11: Calibration and Validation of Watershed Models (e.g. DHSVM, UBC) for Basins of Interest
DR-12: Monitoring of Biafo Glacier of Karakoram Using Remote Sensing and Geographical Information System (GIS) Techniques.
DR-13: Climate Change: Implications and Adaptation of Water Resources in Pakistan
DR-14: Climate Change and Wheat Production in Pakistan: Calibration, Validation and Application of CERES-Wheat Model.
DR-15: Climate Change and Rice Production in Pakistan: Calibration, Validation and Application of CERES-Rice Model.
DR-16: Climate Change and Agriculture in Pakistan: Adaptation Strategies to Cope with Negative Impacts.

NEPAL

NDR-1: Climate Change and Agriculture in Nepal
NDR-2: Climate Change Scenarios for South Asia & Central Himalayan region Based on GCM Ensemble
NDR-3: Climatic Changes: Impacts on Hydrology and Water Resources of Nepal
NDR-4: Climate Profile and Observed Climate Change and Climate Varibility in Nepal
NDR-5: Climate Change Scenarios for Nepal based on Regional Climate Model RegCM3

Appendix V: Funding sources outside the APN

There was no direct funding for this project from sources other than APN. However, in kind support was provided by the four participating organisations (GCISC, PMD, DHM, BUP) from Pakistan, Nepal and Bangladesh in terms of the time of their scientific staff, use of their institutional facilities, logistics support during the organisation of Regional Workshops and administrative support, as and when necessary.

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1. Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy
2. University of Georgia, Griffin. Georgia, USA
3. Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia

ICTP also covered the participation costs (travel and per diem) of some of its scientists participating in two of the Regional Workshops. Besides, it gave particularly favourable consideration to the project members for participation in various workshops and training courses etc. organised at Trieste by its Physics of Weather and Climate section.

Appendix IV: Glossary of Terms/ Acronyms

APN	Asia-Pacific Network for Global Change Research, Kobe, Japan
AOGCM	Atmosphere-Ocean Global Circulation Model/Modelling
AR4	IPCC, Fourth Assessment Report (2007)
BUP	Bangladesh Unnayan Parishad, Bangladesh
BTOPMC	Blockwise Use of TOPMODEL with Muskingum-Cunge Routing
BSMRAU	Bangabhandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh
CAPaBLE	'Scientific Capacity Building/Enhancement for Sustainable Development in Developing Countries' Program of APN
CRP	Coordination Research Program
CVT	Coordinated Varietal Trials
CC	Climate Change
CCS	Climate Change Scenario
CSM	Crop Simulation Model/Modelling
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
CRU	Climate Research Unit, University of East Anglia, UK
DEM	Digital Elevation Model
DHM	Department of Hydrology and Meteorology, Nepal
DHSVM	Distributed Hydrology Soil & Vegetation Model
DSSAT	Decision Support System for Agro-technology Transfer
DDC	Data Distribution Centre, IPCC
DJFM	December, January, February, March
ECMWF	European Centre for Medium-Range Weather Forecasting
ERA15	ECMWF 15 years Reanalysis Dataset
ERA40	ECMWF 40 years Reanalysis Dataset
ECHAM	GCM of Max Planck Institute, Germany
FVGCM	Finite - Volume General Circulation Model
GCM	General Circulation Model/Global Climate Model
GSL	Growing Season Length
GCISC	Global Change Impact Studies Centre, Islamabad, Pakistan
GIS	Geographic Information System
GHG	Greenhouse Gases
GISST	Globally Interpolated Sea Surface Temperature
GLCC	Global Land Cover Characterization
GTOPO30	Global Topography data with horizontal grid spacing of 30 Arc-Second
HadAM3P	Hadley Centre Atmospheric General Circulation Model 3P
HadCM3	Hadley Centre Coupled Model, Version 3
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modelling System
HFAM	Hydrocomp Forecast and Analysis Model
HKH	Hindukush-Karakoram-Himalaya
IPCC	Intergovernmental Panel on Climate Change
ICTP	Abdus Salam International Centre for Theoratical Physics, Italy
JJAS	June, July, August & September
MM5	Mesoscale Model Version 5 developed by NCAR
MIT	Massachusetts Institute of Technology, USA
MPI	Max Plank Institute, Germany
NARC	National Agriculture Research Centre, Pakistan
NASA	National Aeronautics and Space Administration, USA
NCAR	National Centre for Atmospheric Research, USA
NDSI	Normalized Difference of Snow Index
ppm	parts per million
PMD	Pakistan Meteorological Department, Pakistan
PRECIS	Providing Regional Climate for Impact Studies, (RCM)
PWC	Physics of Weather and Climate Centre, ICTP

RCM	Regional Climate Model/Modelling
RegCM3	Regional Climate Model, Version 3, ICTP
RMSE	Root Mean Square Error
SRES	Special Report on Emission Scenarios
SST	Sea Surface Temperature
TAR	IPCC Third Assessment Report, 2001
TM	Thematic Mapper
UBC	University of British Columbia, Canada
UGG	University of Georgia, Griffin, Georgia, USA
WSM	Watershed Simulation Model/Modelling
WRF	Weather Research and Forecasting Model developed by NCAR
WatBal	Water Balance Model
WAPDA	Water and Power Development Authority, Pakistan
WUE	Water Use Efficiency