Tropical forests and adaptation to climate change

In search of synergies

Editors

Carmenza Robledo, Markku Kanninen, Lucio Pedroni

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Foreword

Vulnerability to natural disasters has increased tremendously during the past 25 years and their effects disproportionately affect poor people. Natural disasters, such as storms, especially tropical cyclones, floods, droughts, forest fires, and landslides, affect the poor more severely because they are often forced to live in areas that are more susceptible to natural hazards. With few alternatives within their reach, the poor often make their living on steep hillsides, or low-lying riparian and coastal areas that are exposed to landslides, mudslides, floods and tidal waves. An increasing number of these fragile sites are facing rapid environmental degradation including erosion, reduced soil fertility, declining quality and availability of freshwater, increase in pests and diseases, and loss of biodiversity. Poor people generally do not have the savings or access to credit to mitigate these risks, and even fewer assets to rely on in such hard times.

Climatic variables are increasingly considered as a determinant factor in the development process. It is now well recognised that many developing countries, particularly in the tropics, are more exposed to extreme events and that they are likely to be more vulnerable than countries in other regions. This is especial relevant for poor households living in these countries because, in general, their livelihoods count with a much lower adaptation capacity.

Current changes in the climatic system tend to increase the vulnerability of livelihoods in two main ways: First, due to the fact that many of such livelihoods are exposed to more frequent and intense extreme events causing increasingly negative impacts. The second reason is related to the long-term impacts of changes in temperature and rain patterns. Some potential impacts are loss of land as a consequence of sea rise, loss of arable land due to extended drought periods, loss of food or other basic goods and in general an important reduction of the production basis of the poor. Understanding the interrelations between changes in the climatic system and development is therefore crucial for increasing adaptation capacity at the local level. This represents a challenge for scientists as for policy makers and those engaged in development cooperation.

In recognition of the need to establish a bridge between science, policy making and development cooperation, the Swiss Foundation for Development and International Cooperation (Intercooperation), the Centre for International Forestry Research (CIFOR), and the Tropical Agricultural Research and Higher

Education Center (CATIE), with the financial support of the Swiss Agency for Development Cooperation (SDC), organized in March 2004 in Turrialba, Costa Rica an international workshop on "*Adaptation to Climate Change, Sustainable Livelihoods and Biological Diversity*".

The book we present here encompasses the discussions and conclusions made in the workshop and presents in addition some specific inputs from science and policy-making on the subject matter. As one of the initial efforts in linking climate change, sustainable livelihoods and biological diversity, the book opens up challenges to scientists and practitioners to commonly assess the needs of poor livelihoods to successfully cope with climate change and to bridge the gap for a meaningful implementation of lessons learned at the level of the field. It is hoped that the book can make a significant contribution towards a better understanding of the future challenges in development cooperation to help adapting poor households to the hazards of climate change.

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Generating climate change scenarios at high resolution for impact studies and adaptation: Focus on developing countries

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Generating climate change scenarios at high resolution for impact studies and adaptation: Focus on developing countries

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1. Introduction

As defined by the Intergovernmental Panel on Climate Change (IPCC), "adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts" (Watson *et al.*, 2001). Such adjustments require the availability of bioclimatic scenarios that adequately represent the local conditions in a changing climate system.

In human systems, private decision makers and public agencies or governments undertake adaptation (Ahmad *et al.*, 2001) and it requires sound scientific information. Climate change scenarios are built from a baseline data set characterising the current climate plus projections for possible future climatic means and event frequencies. The latter typically are based on a well-defined set of socio-economic and demographic assumptions resulting in scenarios of greenhouse gas emission (Nakicenovic *et al.*, 2000). The IPCC's Third Assessment Report (TAR) Working Group II Report on Impacts, Adaptation, and Vulnerability (Ahmad *et al.*, 2001: 17) finds that "because the available studies have not employed a common set of climate scenarios and methods, and because of uncertainties regarding the sensitivities and adaptability of natural and social systems, the assessment of regional vulnerabilities is necessarily qualitative". This is particularly true for developing countries. The problem is exacerbated by the expectation that those with least resources have least capacity to adapt and are most vulnerable to future climate change (Watson *et al.*, 2001).Therefore, capacity building and improvements in outreach activities are needed to support informed decision making in adaptation to cope with the impacts of climate change. This is particularly relevant in countries often already suffering from insufficient means and economic resources, such as the least developed countries.

How then should impact studies, vulnerability assessments and adaptation strategies be developed? To develop sound adaptation strategies, quantitative assessments of climate change impacts on entire regions, including ecosystems and socio-economic systems, are needed. They form the basis for assessing the vulnerability. Vulnerability here is understood as defined in the IPCC TAR Working Group II Report, "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (McCarthy *et al.*, 2001).

Quantitative information is required not only on the climate and its possible, anticipated changes but also on the responses of the affected systems. The required data include those on climate and climate change, soils, agro-ecology, and socio-economic aspects. The difficulty of obtaining and managing these four types of data increases in that order. A vast investment has been made in collecting, managing, standardising and modelling climate data, and because of this they are definitely the easiest type of data to manage. Yet considerable efforts have been made in all the other areas as well, albeit to a highly variable extent. As a result, some data are available for all needed types and can be used to quantitatively assess climate change impacts and the sensitivities of the systems to adverse effects of climate change. These quantitative results are required for identifying the vulnerability of a system. Collapse will occur whenever a sensitive system is affected to such a degree that its capacity to adapt to the new climate is exceeded. Thus, all the data and the quantitative analysis performed on them form an indispensable basis from which to formulate possible adaptation strategies on how to cope with the identified vulnerabilities.

It is important to make assessments for adaptation using compatible data sets. Studies need not use the same climate models provided they use ones with at least two different sensitivities and scenarios of the Special Report on Emissions Scenarios (SRES), either mid-range A2/B2 or the full range of A1fi/B1 or A1fi/A1T. This is imminently feasible but it is important that the study also use population, land use or economic development assumptions that are compatible with the climate scenario. This may be more difficult at a local scale but it is possible. Arnell *et al.* (2004) have developed a fine-scale set of socio-economic scenarios that can be used at the country and even smaller scale regional level to complement the SRES emission/climate scenarios.

We show in this paper that, with existing techniques and approaches, bioclimatic scenarios at high resolution can be generated in developing countries despite the many remaining gaps and challenges, which are also discussed here.

2. Requirements

We believe that many, if not most, of the data requirements can be met in developing countries with a minimum of extra effort.

2.1 input data sets and processing capacities

Simulation results from Atmosphere-Ocean General Circulation Models (AOGCMs) should be made available to researchers involved in downscaling to local models ("downscalers") and should be based on standard emission scenarios such as in the IPCC SRES (Nakicenovic *et al.*, 2000). Downscaling typically needs AOGCM results in long runs and at high temporal resolution, for example, 6 hours or daily. For other applications, such as stochastic weather generation, it may be sufficient to have the monthly means only. Whenever possible, one should favour results from AOGCM models that are well tested and state-of-the-art.

It is possible to run regional climate models with boundary conditions constrained by Global Climate or General Circulation Model (GCM) output on high performance PCs or with parallel processing using an array of PCs forming some cluster, or connected via local area networks. These are within the capacities of many institutions in developing countries.

Local or regional databases containing records from weather stations within and adjacent to the region of interest should be made available to researchers needing these data. There has been a lamentable tendency in recent years for national meteorological institutions to start charging exorbitant prices for data, even though in many cases other organisations collected the data.

Digital terrain models with spatial characteristics supporting those of regional climate models and bioclimatic scenarios are available and should be used to account for orographic effects (see NASA, 2004). This innovation is particularly welcome because many areas in the developing world are poorly surveyed and the cost of digitising from local maps is very high.

2.2 Data considerations

Characteristics of the data sets and bioclimatic scenarios generated may vary strongly depending on the actual system under study. The resolution and extent of the needed data are typically given by the input requirements of the involved impact models where the following points must be considered.

Necessary temporal resolution ranges from hourly, daily, monthly, and seasonal, up to a year; in the case of landscape models sometimes even to a decade. Spatial resolution may range from 100 m, for example, in an orographically highly variable terrain such as mountains, up to 10 km in the plains.

Temporal extent ranges from 1 year for annual crops up to 3,000 years. Forest succession requires 600-800 years to reach a new equilibrium between climate and vegetation (e.g., Fischlin *et al.*, 1995), while soil dynamics are so slow that several millennia are required to reach a new steady-state after climate has changed (e.g., Perruchoud *et al.*, 1999). Spatial domains may range from 10 km up to sub-continental and continental dimensions.

2.3 Other considerations

Appropriate scientific personnel with the necessary know-how and skills are a prerequisite to conduct the task of generating reliable state-of-the-art bioclimatic scenarios. Furthermore, particularly in developing countries, institutional capacities, which provide the specific computing and communication facilities, are also necessary. Finally, in many developing countries, it is unfortunately not a matter of course to readily access the current scientific literature, in general a necessity for any fruitful scientific environment.

3. Current techniques and approaches

In some cases, analogues can be used. These rely on hypothetical changes to a regional climate, such as an overall temperature increase added on to an existing climate surface. They are simple and quick to evaluate and can give an assessment of the effects of the hypothetical change. Yet, since an analogue or arbitrary change imposed on a climate surface does not necessarily have any scientific basis, bioclimatic scenario generation should be used with caution. Whenever possible, GCM results should be used to reflect the expected changes and spatial distribution.

AOGCM output has a relatively coarse spatial resolution compared to the scales at which many impacts must be assessed and therefore must be downscaled before being applied to the development of regional- and local-scale bioclimatic scenarios. Three principal methods are available for obtaining accurate downscaled results. First is the use of GCM output to determine a change factor or "delta", which then is superimposed on existing climatology. The second method is dynamic downscaling or regional climate modelling. The third method, statistical downscaling, includes more complex regression techniques than the delta approach, as well as weather typing and generation. Downscaled data can be refined further and localised by using accurate surface information that captures fine-scale variations in topography and orographical features, and through detailed historical records of observed climate means and variance.

3.1 Delta change

The simplest use of AOGCM results is to use the predicted future differences as a Change Factor (CF), or delta, to modify an interpolated climate surface. This is relatively easy to do but has inherent errors, particularly in mountainous regions (Gyalistras *et al.*, 1994; Fischlin, this volume). As with all statistical approaches, the downscaling is only as good as the underlying surface derived and interpolated from observed climate.

3.2 Dynamical downscaling (Regional Climate Modelling)

In dynamical downscaling, global model outputs are used as boundary conditions to drive regional climate models that explicitly simulate the physical dynamics of the regional climate system. Regional Climate Models (RCMs) typically cover areas that range from a region within a country up to a small continent. Downscaled forcing sets the boundary conditions for each step of the regional model from the GCM. This approach allows the simulated local climate to respond to the GCM output in a manner that is meteorologically and hydrologically consistent, producing climate projections at scales as fine as 5-50 km. Comparing RCM, GCM, reanalysis and observational temperature shows that RCMs potentially can improve GCM simulations even beyond what is possible with reanalysis.

Downscaling GCM output via RCMs has clear advantages in terms of consistency and scientific understanding of the climate system. However, dynamical downscaling is currently limited by two factors. First, RCMs require that the GCM output used to force the boundary conditions has a temporal resolution of 6 hours and vertical resolution for key variables including temperature, geopotential, wind speed and direction. Very few GCMs provide output at this level of detail and the large file sizes require significant storage (on the order of ~80 GB per decade of 6 hour GCM input to the RCM). Second, RCMs also require a significant investment of time and computing resources. For this reason, dynamical downscaling requires high-speed processors and can be applied only to limited periods, rather than the full 100-year timeline out to 2100 that most impact studies require and that most AOGCMs cover.

Downscaling grids can be nested at various levels to gain the maximum precision at the points of most interest. In practice, it is doubtful that accuracy greater than 2 km can be achieved reliably even with highly accurate DTM data. The models can be nested within the grid at a higher level, providing boundary conditions to the embedded higher precision grid. This seems to imply that a generalisation to a 'quadtree' grid representation[1] should be possible to maximise the boundary condition information flow and the precision in the area of interest. However, no example of an actual application of this approach has come to the authors' attention.

[1] A quadtree representation is a geographic information systems (GIS) device to allow pixel size to vary across a grid. It relies on sequential subdivisions of pixels into four smaller ones until the required area is defined.

The data volume for specifying boundary conditions could be reduced if only the boundary cells are requested. These could be specified as row, column and altitude and by variable to bound the nested model volume. In the case of a quadtree-nested model, this would not necessarily be a rectangular box. Agencies running GCMs would need to develop an automated method of extracting such results, but this kind of system would be a significant advantage to dynamic downscalers with limited resources.

3.3 Statistical downscaling

Statistical downscaling methods lack the explicit solving of the climate system dynamics inherent in regional climate models. However, these methods have the advantage of low-cost and rapid simulation of climate features at sub-grid scale using empirical relationships developed between modelled and observed climate variables (e.g., von Storch *et al.*, 1993; Gyalistras *et al.*, 1994; Hewitson and Crane, 1996; Wilby and Wigley, 1997; Wilby *et al.*, 1998a; b). Downscaling is accomplished through developing relationships between historical observed variables at local scale, typically long-term records from weather stations, and modelled climate patterns over the region. Three approaches are commonly used.

The first is a more sophisticated approach than delta change and involves developing linear and non-linear transfer functions that range from traditional interpolation and canonical correlation techniques (e.g., Gyalistras *et al.*, 1994; Gyalistras and Fischlin, 1999) to innovative artificial neural networks (e.g., Widmann *et al.*, 2003). These regression approaches are extremely flexible. They can incorporate the influence of multiple GCM output variables on surface variables, ranging from standard temperature and rainfall projections to impact-relevant indices. Examples of such indices include human health thresholds, soil moisture, streamflow and other hydrological indicators, and extreme event frequencies (e.g., Hayhoe *et al.*, 2004).

The second approach uses GCM data to drive stochastic weather generators (Wilks and Wilby, 1999). Weather generators are of great importance for realistic scenarios. Weather generators can be used in various forms and also can be nested and combined with both global and regional modelling to generate monthly, daily and hourly weather data. This is critical in the case of statistical downscaling, because GCM data are best downscaled to monthly climatic parameters (Gyalistras and Fischlin, 1999; Fischlin, this volume). Yet an application such as an impact study on agricultural crops may require daily temporal resolution (Riedo *et al.*, 1999). Most temperate studies can use a first or 1.5 order model comfortably (Richardson and Wright, 1984; Hutchinson, 1987) but, for the tropics, Jones and Thornton (1993) showed that a third order model[2] was necessary in many environments.

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[2] The order of a Markov model is the number of steps considered in calculating the transition probabilities for the process. In a typical daily rainfall model, a first order model considers only what happened yesterday. A third order model considers the last 3 days. A 1.5 order model considers the day before yesterday only if it rained yesterday.

The last approach, called 'weather typing', classifies recurrent large-scale atmospheric circulation patterns and their relationship to local climate (Wilby, 1995).

An advantage of a statistical approach is the potential to generate a number of realisations in order to assess uncertainty in regional-scale predictions at the same spatial scale as the historical observations used to develop the relationships.

Lacking any treatment of the physical dynamics in the system, the validity of statistical relationships developed under current climate conditions for projecting the future under very different conditions often is questioned. However, comparison of 50 x 50 km Parallel Climate Model- (PCM) driven RCM simulations with statistical downscaling combined with bias removal (see Wood *et al.*, 2004) shows that careful statistical downscaling, particularly when combined with bias removal using a gridded and detailed historical database (Gyalistras and Fischlin, 1999; Gyalistras, 2002; 2003), can produce highly similar results to an RCM with much less computational effort. The same objection applies to weather typing because the downscaling depends on relationships existing now. If climate change produces weather types that do not exist today, models may be extrapolated into ranges for which they are not appropriate. However, weather typing including the GCM results ensures that this eventuality is covered.

3.4 Combining and integrating downscaling methodologies

Often, delta change and regression approaches of statistical downscaling can be combined; see Gyalistras and Fischlin (1999), Fischlin (this volume) and the Statistical Downscaling Model (SDSM) software developed by R. Wilby, which is freely available[3]. Combining stochastic weather generation with regression-type analysis addresses the issue of variance deflation common to regression-only schemes. Careful comparison of retrofitted results from this technique with actual measurements showed that combining stochastic weather generation with downscaling techniques can yield results that fit observed daily temperature and precipitation not only in their means but also in their inter-daily, inter-monthly, inter-seasonal and inter-annual variability (e.g., Gyalistras, 1997).

Combining stochastic weather generation with weather typing, as in Jones and Thornton (2003), provides a rapid way to downscale over large areas. Regression models of the stochastic weather generator are fitted within pre-classified weather types and used to determine the parameters point-by-point depending on present or future indicated climate normals. Weather types can be classified from AOGCM predictions to avoid fitting only to present-day weather patterns.

Current AOGCMs as well as RCMs still fall short of matching the high spatial resolution requirements of most impact models. Thus, some of the most

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[3] https://co-public.lboro.ac.uk/cocwd/SDSM/

promising techniques are a combination of dynamic and statistical downscaling techniques. Such an integrated methodology attempts to use each of the available techniques where they provide the most robust results (Gyalistras and Fischlin, 1999; Fischlin, this volume). For instance, the results from dynamical downscaling are used at a spatial resolution where this method provides the most robust estimates. For finer-scale estimates required as input to many types of impact models and assessments, on the order of 4 km^2 or smaller, statistical downscaling can overcome the remaining insufficient spatial resolution by "introducing" into the scheme the essential information from the local weather records. Moreover, using stochastic weather generators whose parameters are driven by the statistical downscaling techniques overcomes the lack in temporal resolution (e.g., Gyalistras and Fischlin, 1999). Finally, using temporal extrapolation techniques derived from the relationships obtained via the statistical downscaling obtains transient climate change scenarios for nearly any temporal extent, even beyond that of the current AOGCM simulation time, that is, up to many centuries into the future (Gyalistras and Fischlin, 1999; Fischlin, this volume).

3.5 Refining downscaling methodologies

All the downscaling methods described above rely on interpolated climate surfaces that, in turn, rely on accurate Digital Terrain Model (DTM) information. Until recently, a reliable DTM data set for the globe has not been available. TGP-006 (NOAA, 1984) has been available for some time at a resolution of 10 arc-minutes but had serious failings and is not recommended for mountainous regions. GTOPO30 (USGS, 1996) was much better at a resolution of 30 arc-seconds but still carried some of the failings of TGP-006 in certain areas. Nevertheless, it is used widely. Where no DTM is readily available, topographic maps of the region to be studied often have to be digitised. This is costly and time consuming. With the release of the Shuttle Radar Topographic Mission data (SRTM) (NASA, 2004), a global 90-m DTM has become available. Jarvis *et al.* (2004) have reprocessed these data and checked them against accurate digitised data from Colombian topographic maps at a scale of 1:10,000. The authors have found that the remotely sensed data are highly reliable.

Regardless of the DTM, climate information is needed at points without any weather records. Then, to cover all the points of interest, various climate interpolation techniques can be used. Jones *et al.* (1997) and Jones and Thornton (2000) used inverse square distance weighting, which is fast and conservative where large data gaps occur but is probably best used at coarse resolutions, as in these global studies. Kriging is a technique widely used in geographical information systems (GIS) but seems not to have found favour with climate interpolators. Sánchez *et al.* (1999) developed an interesting technique using local multiple regression within a river catchment. This ensures that the climate/topography relationships are locally correct but for large areas a smoothing must be applied from one catchment to another. The most commonly used, however, is thin plate smoothing. Hutchinson (1989) first applied this technique to climate data.

4. Strengths and weaknesses in climate data, models and techniques

4.1 Data records

In the study of climate, we rely on both observed and modelled data in order to chronicle the climate we have observed over the region in the last century and, calibrated on observed climate, we attempt to project characteristics of future climate resulting from a range of greenhouse gas emissions from human activities.

Long-term weather station records offer the best view of what climate has been like and how it has changed already. Studies using observed station data in the US Midwest have shown how the length of the frost-free season has increased by as much as 2 weeks since the beginning of the century, mainly due to earlier dates for the last spring freeze (Kling *et al*., 2003). These studies have identified an increase in heavy rainfall events, such that these are now twice as frequent as during the early part of the century (Kunkel *et al*., 1999). Lake records show a significant decrease in ice extent, particularly on inland lakes, as well as a tendency towards earlier seasonal cycles in the North American Great Lakes (Lenters, 2001; Kling *et al*., 2003).

Many other proxy data sources also exist, such as ice cores, tree rings, pollen records from lake sediments or bogs, the distribution and abundance of insects and other species from the taxon *Arthropoda* etc., which all may be used to characterise past climates. All these techniques offer the advantage of reaching far into the past, yet they still need all the data from the instrumental period in order to become useful for precise, quantitative projections.

Although each source of data has certain strengths, each also includes shortcomings that limit application to regional projections of climate change.

4.2 Weather station data

Observations are the primary data source used to characterise current and historic climate. For North America and Europe, temperature and precipitation records from individual stations are the most detailed and highly resolved data available, often extending back over 100 years. These stations offer the most essential opportunity to characterise climate at the local and regional level with maximum precision. Records of lake levels, ice cover, and sea level also extend back over the past century.

As useful as instrumental data are, however, station records are susceptible to significant uncertainty introduced by urban heat effects, changing instrumentation and observers, and the uneven spatial distribution of the stations. In addition, many stations solely provide precipitation and temperature data at 24-hour intervals. These variables do not adequately reflect many of the changes in climate. However, only a limited number of stations (primarily airports) report pressure, humidity, wind speed and cloud levels. An even smaller number of stations (for example, only three in the state of Illinois in

USA, and often none in developing countries) release rawinsondes or weather balloons that provide vertical profiles of temperature and pressure at that site.

Weather station coverage in developing countries is highly variable but almost never equal to that of the developed world. It closely follows the pattern of population and significant gaps occur at high altitudes, in forested or desert areas and where access is poor. Although the total number of historic stations in a country may appear adequate, often only a small subset are operating at any given time. It is thought to be a difficult, costly, long-term problem to remedy the gaps by augmenting the permanent national system grid. However, by placement of short-term stations in critical areas, this can be overcome. Careful time series analysis can correlate with existing stations and useful interpolation statistics may be gained from just a few years' data.

4.3 Reanalysis and satellite data

Reanalysis data from the US National Center for Environmental Prediction[4] and the European Centre for Medium-range Weather Forecasts[5] are another source of data used to characterise past and current climate. Gridded reanalysis data provide many of the atmospheric variables needed to characterise climate over the past century that are not available from station data. In addition to surface-level temperature and precipitation, reanalysis variables include vertically resolved pressure levels, geopotential heights, humidity, cloudiness, winds, vorticity and radiative forcing. Weather models constrained by station and rawinsonde observations at 6-hour intervals are used to calculate these variables. However, these data are limited by the fact that detailed calculations over the US, for example, only began in 1958. In addition, the data are gridded to a relatively coarse spatial resolution of 1° and only saved as monthly averages that severely limit their application to climate studies. Finally, although the weather models were constrained to fit observed data, these are model calculations and not actual observations.

Data from satellite observing stations mitigate the need for model intervention and interpolation. Many of the problems with reanalysis data are being addressed and should be reduced greatly over the next decade as global satellite coverage becomes denser, instruments are duplicated on multiple satellite platforms, and increasingly accurate and high-resolution (both in terms of time and space), full vertical profiles of clouds, wind, temperature, radiation and other indicators of atmospheric dynamics become available. Satellite data will provide a much tighter constraint on reanalysis than the few profiles currently available from rawinsondes and are likely to improve the accuracy of reanalysis data, particularly at finer spatial scales.

Global coverage by satellites already has supplied several decades of continuous data on temperature, ozone, radiation, sea surface temperature (SST), winds, clouds, land-use change and other key variables that describe

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[4] http://www.dss.ucar.edu/pub/reanalysis/

[5] http://www.ecmwf.int/research/era/

the earth-ocean-atmosphere system. Satellites provide global coverage that is particularly valuable in regions where reanalysis data are not available and ground-based weather stations are sparse. Although plagued in the past by validation issues and discontinuities in instrumentation, recent collaborative efforts to place duplicate and complementary instruments on a suite of inter- and multi-national satellites (for example, the A and B trains, otherwise known as the PM and AM Constellations) offer hope for building consistent global databases of observed climate at fine spatial and temporal scales.

4.4 Global climate models

The foundations for future climate projections are the three-dimensional coupled GCMs that incorporate the latest understanding of the physical processes at work in the atmosphere, oceans and the Earth's surface. Models are being enhanced constantly as our understanding of climate improves and as computational power increases, enabling additional components of the Earth-ocean-atmosphere system to be dynamically linked and resolution to increase. As output, they produce gridded projections of precipitation, temperature, pressure, cloud cover, humidity and a host of other variables at temporal resolutions ranging from daily to monthly.

Recent advances in AOGCM modelling have produced a suite of models (e.g., PCM, HadCM4 and ECHAM5) that produce realistic simulation of surface heat fluxes, observed global average temperature and precipitation (within 1°C for temperature and a slight overestimate of precipitation by 0.1-0.4 mm/day), and El Niño SST occurrences and the standard deviation of anomalies close to those observed. In particular, HadCM3 plus its successors and PCM are the only models to have completed total forcing runs (including greenhouse gases, aerosols, volcanic eruptions, ozone and solar changes) that successfully reproduce observed variations in global temperature over the last century, although still with regionally varying biases in absolute values of temperature and precipitation.

A key uncertainty in climate model projections is the question of to what extent the model captures spatial variations in change at the regional level required for input to impact assessments and fine-scale bioclimatic scenarios. In terms of regional change, impacts are often dependent on small-scale processes and localised features of climate that may not be well represented when averaged on the coarse resolution of a typical GCM grid, which ranges from 2.5–5°. Climate in areas with rapid changes in elevation or important orographic features is not well characterised at the grid resolution of current global models. Recent high-resolution climate model simulations (e.g., T106 using the ECHAM5 model, 250 km^2 using the NCAR/PCM model, and T1279 or ~10 km^2 on the Earth System Simulator) address many of these spatial scale issues. However, improvements in model resolution below ~20 km^2 currently are limited by our physical understanding of small-scale processes, particularly those of importance in the surface or boundary layer that drive variations in surface impacts on scales of ~100-1000 metres.

As model resolution increases, regionally varying biases in absolute values of temperature, humidity, precipitation and other key variables are reduced but not eliminated. And finally, many variables needed for regional scenarios and impact assessments are not simulated directly by AOGCMs (e.g., lake levels, extreme events, biosphere and soil characteristics). For these reasons, downscaling and bias removal techniques will remain an essential step in applying even future high-resolution GCM projections to regional-level climate projections and impact assessments.

4.5 Integrated assessment models

Integrated assessment models (IAMs) appear attractive because they are able to dynamically integrate socio-economic and demographic data with land-use change, technology, emissions and climate. The primary strength of IAMs is their ability to capture the full cycle of feedbacks between human activities and the Earth-ocean-atmosphere system, revealing links that may not have been recognised nor fully understood before. Because of their extremely low resolution that is required for efficient linking of multiple human and physical systems, however, IAM-generated climate change scenarios cannot be considered a replacement for those obtained from AOGCMs. Their use is advisable only if the data are made available in a form that is fully comparable with those from the GCM. The latter represents a considerable challenge for any downscaling methodology, since it would have to overcome the shortcomings of the coarse IAM. Since upscaling is easier than downscaling, IAMs may be used better to check that assumptions used within a scenario generation are consistent with the global background.

5. Gaps and opportunities

The national circumstances of developing countries vary strongly with respect to those scientific and institutional capacities that deal with climate change in general, as well as climate modelling and adaptation in particular. The following statements should be understood accordingly, realising that the presented list is not exhaustive.

5.1 Gaps

- **Lack of qualified personnel** results from (i) scarce funding for education, (ii) deficiencies in the educational system itself (in particular at the university level) and (iii) insufficient professional prospects for scientists in research and applied science.
- **Lack in the continuity of expert and responsible staff and administrations** is often due to frequent discontinuities and changes at governmental levels.
- **Responsibilities are dispersed** over many institutions among which coordination is often lacking.

- There is a **lack of centralised or co-ordinated data collection**, often resulting in incompatibility between data-set formats. Unfortunately, too often this makes data unusable for the purpose for which they were originally collected, if indeed the individual organisations are willing to share with others outside their immediate circle.
- There is a **distinct lack of meteorological stations and monitoring of climate** particularly at high elevations. The recent analysis on the adequacy of the global observing system by the Global Climate Observing System (GCOS, 2003) is to be considered in this context.
- **Insufficient dialogue** exists between various involved communities such as data collectors, climate modellers, and impacts and adaptation specialists.
- Reanalysis calculations are the primary source for validating RCM performance over the historical period before using the RCM to project future climate change. **However, few or no reanalysis data exist for developing countries**. Hence, it would be most desirable if the weather models currently used over the US and/or Europe to provide reanalysis data could be adapted for other continents. Even a few years of reanalysis data (e.g., 2005-2010) would provide enormous potential to validate region-specific RCMs over developing countries.

It is believed in general that progress in addressing climate change will only be achieved in developing countries if there is multi-sectoral and inter-institutional participation in climate change research, in know-how development and maintenance, and in the implementation of adaptive measures. The various stakeholders, including the scientific community, have to foster this broad cooperation.

5.2 Opportunities

- **Utilise the capacities and findings of existing research institutions and groups** that are working on modelling climate change and impacts in developing countries.
- **Take advantage of existing co-operation** of research groups from developing countries with groups from developed countries, or in the framework of bilateral state-to-state cooperation.
- **Take advantage of the opportunities offered by programmes** developed by multilateral/regional intergovernmental organisations in the area of, or relevant to, climate change.

6. Implications for adaptation

Addressing climate change and its impacts will not receive higher political priority in national agendas in developing countries until it has been recognised as an issue of major relevance for development, particularly sustainable development, that may have important cross-sectoral impacts. Only if this requirement is met will activities, especially adaptation activities, gain higher priority in national policies. Thanks to high-resolution climate change scenarios at regional and sub-continental levels, adverse impacts and vulnerabilities can then be identified. This generates the needed basis to define adaptation strategies. Hence, in developing countries, the findings of this work have to be brought to the attention of national governments, policymakers, national development planners, regional organisations, the scientific community, investors and donor countries and institutions.

The effects of climate change in agriculture and forestry can be highly localised. Jones and Thornton (2003) showed that maize yields could vary from increases to almost certain crop failure within ranges of tens of kilometres. This implies that broadscale policies may not be appropriate over national or regional scales but must be tailored to specific locations and systems. Other studies of scale showed that overall estimates of climate impacts on a region vary greatly depending on the degree to which social groups, sectors and regions are resolved (O'Brien *et al.*, 2004).

It is necessary therefore to carefully identify end users for whom findings and recommendations on adaptation are to be developed. The particular needs of the identified end users should be taken into account from the very beginning of such a project, with ongoing dialogue ensuring that the needs of the impact community and decision makers are met, while they in turn inform the climate science and analysis (Cash and Moser, 2000). Other important elements that will sustain adaptation are: (i) the extension of educational services and the dissemination of information on climate change and (ii) the distribution of information for daily decision making within civil society.

Finally, regional- and country-specific impact assessments should encompass the full range of possible scenarios of future climate change, particularly those resulting from scenarios of low up to high greenhouse gas emission. Such information will provide the necessary basis for decision makers to tread a careful and optimal balance between mitigation and adaptation, as well as identifying key areas of vulnerability and hence providing guidance for apportioning funds for adaptive measures at the regional to local level.

7. Recommendations

Working Group 1, "Generation of Local Climate Change Scenarios", of this workshop agreed to formulate a set of recommendations which address (i) scientific and technological, (ii) institutional, and (iii) socio-economic and political issues.

7.1 Scientific and technical issues

The target audience for these recommendations are national governments and policymakers, in particular national development planners, regional organisations, the scientific community, and investors and donors.

- Observed data sets should be consistent and prepared in a format compatible with the requirements described above. These should be made available in a user-friendly, easily accessible form at the highest resolution possible.
- GCM model results should be readily available in a user-friendly manner to "downscalers" at the temporal resolution required for the various downscaling approaches. The data sets should allow users to select geographic regions and variables of interest to allow for optimal data transfer and use.
- User-friendly downscaling tools, interpolation techniques and stochastic weather generators should be made available to interested scientists. They should be prepared for a PC environment and ideally should be provided with manuals and training offers.
- A clearinghouse website should be established and maintained by appropriate institutions that offers some of the aforementioned tools together with the accompanying manuals in a user-friendly manner. Preferably the IPCC data centres might be ideal institutions to offer such a new service. This website should also foster virtual co-operation and could offer CVS facilities, which support the development of open source software tools.

7.2 Institutional

The target audience for these recommendations are the institutions responsible for national and/or regional science and education.

- National and regional academies are encouraged to make it a priority to provide the resources needed to assist scientists in the dissemination of data and information as stated above.
- Institutions that have proven to be successful in the past in disseminating, coordinating, cooperating and exchanging relevant information and training should be strengthened.
- Scientific institutions, including national academies and similar institutions, are encouraged to promote and find solutions for the financing of exchange programmes involving students from developing countries in climate change scenario generation and impact studies relevant for adaptation.

7.3 Socio-economic and political

The target audience for these recommendations are governments and relevant political organisations and bodies.

- Governments need to recognise that their investments can be protected only if the best available tools that the scientific community can bring forward are used to make sound decisions on generating and implementing adaptation and mitigation measures related to climate change and sustainable development.
- Governments must recognise the need to quantitatively assess climate change impacts in order to enable the identification of vulnerabilities and the development of adaptation measures.

- Governments must recognise the need to generate a range of representative climate change scenarios at the local and regional levels in order to quantitatively assess impacts.
- National and international co-operation should be facilitated to assist the exchange and dissemination of relevant information.
- National institutions responsible for planning and educating must ensure that the results of these efforts are used efficiently.
- Additional resources should be made available at the country level for capacity building on climate change issues.
- Investors and donors as well as host countries of bilateral and multilateral development assistance should aim to include in all projects conducted in a developing country an assessment of the needs for adaptation to climate change based on local criteria.

8. Conclusions

The discussions at the workshop have indicated that high-resolution bioclimatic scenarios can already be generated in developing countries, despite challenges occurring both in personnel and at the institutional level. These scenarios are the first step towards defining adaptation strategies and measures to cope with climate change. If additional, targeted efforts are made based on the outlined recommendations, remaining gaps may be closed relatively easily and the main existing hurdles can be overcome to successfully generate regional climate change scenarios for impact assessments.

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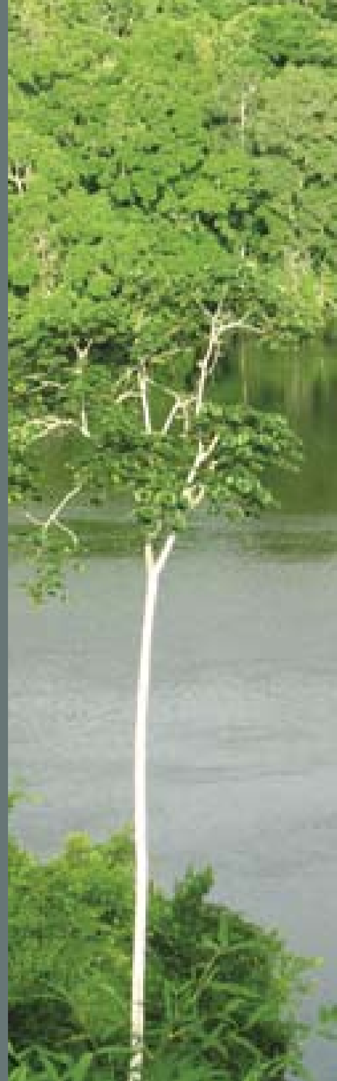
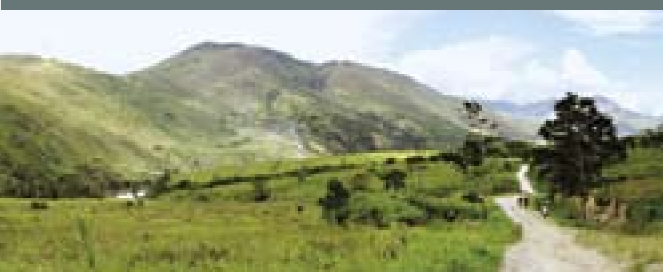
This book encompasses inputs from science, policy making and development cooperation with regard to the linkages between climate change, sustainable livelihoods and biological diversity. It presents experiences, challenges and alternatives to scientists and practitioners for commonly assessing the needs of poor livelihoods to successfully cope with climate change as well as for bridging the gap towards a meaningful implementation of adaptation measures.

It is based on the recognition of the need to establish a bridge between science, policy making and development cooperation with regard to promoting adaptation to climate change and variability at the local level. The Swiss Foundation for Development and International Cooperation (Intercooperation), the Center for International Forestry Research (CIFOR), and the Tropical Agricultural Research and Higher Education Center (CATIE), with the financial support of the Swiss Agency for Development Cooperation (SDC), have jointly worked for a period of two years before completing of this book. Many of the articles included are based on the discussions that took place during the international workshop on "*Adaptation to Climate Change, Sustainable Livelihoods and Biological Diversity*", held March 2004 in Turrialba, Costa Rica.





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