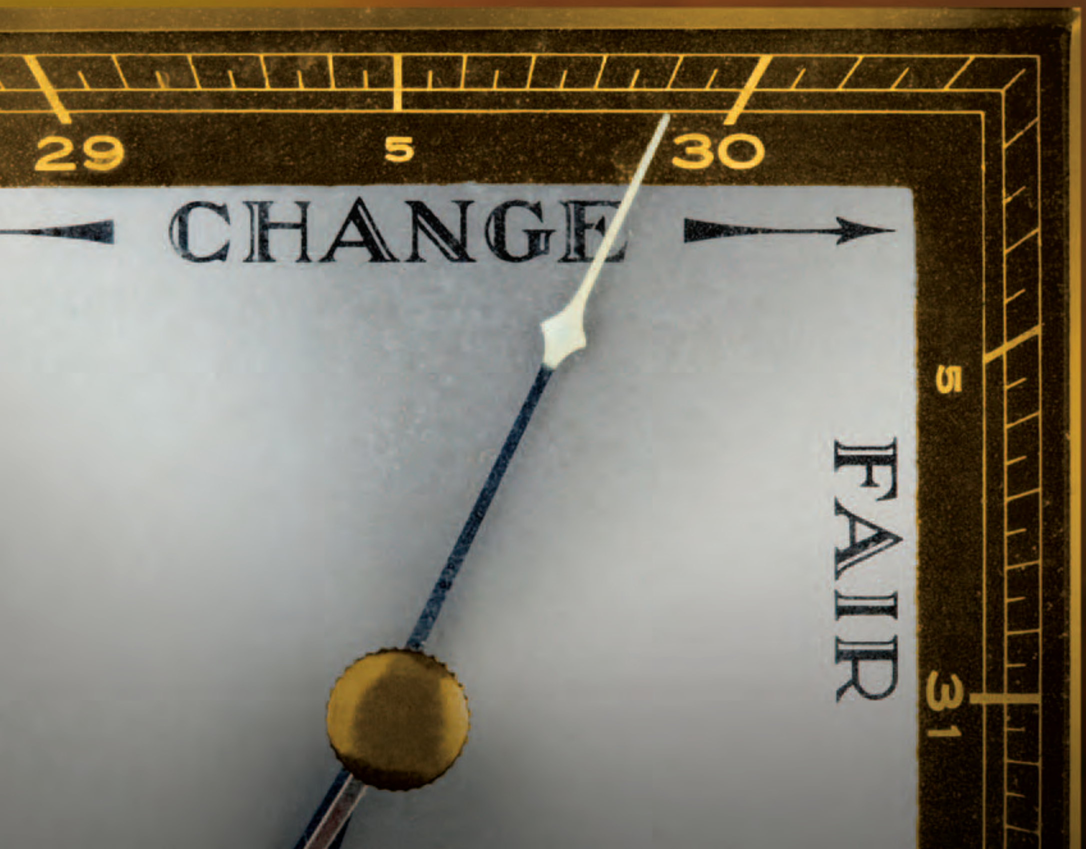
United Nations Development Programme

Formulating Climate Change Scenarios to Inform Climate-Resilient Development Strategies

A Guidebook for Practitioners



UNDP is the UN's global development network, advocating for change and connecting countries to knowledge, experience and resources to help people build a better life. We are on the ground in 166 countries, working with them on their own solutions to global and national development challenges. As they develop local capacity, they draw on the people of UNDP and our wide range of partners.

April 2011

Design: Anvil Creative Group (NY, www.anvilcreativegroup.com)

Contents

FIGURES

TABLES

BOXES

Acronyms and Abbreviations

AR4	(IPCC) Fourth Assessment Report
AR5	(IPCC) Fifth Assessment Report
CIMA	Argentine Research Center of the Sea and the Atmosphere
CRU	Climate Research Unit
DOE	(US) Department of Energy
ENSO	El Niño-Southern Oscillation
GCM	Global Climate Model/General Circulation Model
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
km	Kilometres
km^2	Square kilometres
LECRDS	Low-Emission Climate-Resilient Development Strategies
NCEP	(US) National Centers for Environmental Prediction
NCAR	(US) National Center for Atmospheric Research
NC	National Communications
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
SNC	Second National Communication
SRES	Special Report on Emissions Scenarios
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WRF	Weather Research and Forecasting Model

Formulating Climate Change Scenarios to Inform Climate-Resilient Development Strategies

A Guidebook for Practitioners

This guidebook is part of a series of manuals, guidebooks, and toolkits that draw upon the experience and information generated by UNDP's support for climate change adaptation and mitigation projects and National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) in some 140 countries over the past decade. They are intended to enable project managers, UNDP Country Offices, and developing country government decision makers to acquaint themselves with a variety of methodologies most appropriate to their development contexts in support of the preparation of low-emission climate-resilient development strategies (LECRDs). In a flexible and non-prescriptive manner, they offer detailed step-by-step guidance for the identification of key stakeholders and the establishment of participatory planning and coordination frameworks; generation of climate change profiles and vulnerability scenarios; identification and prioritization of mitigation and adaptation options; assessment of financing requirements; and development of low-emission climate-resilient roadmaps for project development, policy instruments, and financial flows. This publication focuses on the formulation of climate-change scenarios as a tool to inform low-emission climate-resilient development strategies.

Lead authors: Michael J. Puma, Associate Research Scientist, Center for Climate Systems Research, Columbia University/NASA Goddard Institute for Space Studies, and Stephen Gold, Principal Policy and Technical Adviser, Environment and Energy Group (EEG), Bureau for Development Policy (BDP), United Nations Development Programme (UNDP), New York

Internal reviewers: Yannick Glemarec, Director for Environmental Finance/UNDP-GEF Executive Coordinator (UNDP/BDP/EEG), Pradeep Kurukulasuriya, Senior Technical Adviser (UNDP/BDP/EEG), and Yamil Bonduki, Coordinator, National Communications Support Programme (UNDP/BDP/EEG)

Editor: Caitlin Connelly

This guidance document should be referenced as: Puma MJ and Gold S. 2011. *Formulating Climate Change Scenarios to Inform Climate-Resilient Development Strategies: A Guidebook for Practitioners*, United Nations Development Programme, New York, NY, USA.

Foreword

Climate change is a defining challenge of our time, and it is one of the most pressing threats to development today. The poorest and most vulnerable populations of the world are most likely to endure the harshest impacts and suffer disproportionately from the negative effects of climatic changes. In order to best serve the needs of the at-risk communities, we must address climate change through a development lens (and vice versa).

Addressing the possible impacts of climate change is proving to be entirely compatible with the pursuit of sustainable development and the achievement of the United Nations Millennium Development Goals. Our experience at UNDP over the past two decades indicates that the right mix of policies, skills, and incentives can influence behaviour and encourage investments in climate development-friendly activities. To facilitate this, UNDP enhances the capacity of developing countries to formulate, finance and implement national and sub-national low-emission climate-resilient plans that align climate management efforts with development goals and that promote synergies between development and climate finance.

A key task when formulating these plans is the development of climate scenarios. This is the topic of the present UNDP publication, *Formulating Climate Change Scenarios to Inform Climate-Resilient Development Strategies: A Guidebook for Practitioners*, which guides project managers and their team of experts in their efforts to assess the need for climate scenarios, identify existing constraints (due to financial, computing, workforce and scientific limitations), and evaluate and select various approaches to generate a range of prospective climate scenarios.

This guidebook builds on a large range of UNDP's ongoing initiatives to support adaptation to climate change and is part of a series of practical guidance documents and toolkits being developed to support the preparation of low-emission climate-resilient development strategies — LECRDS. This series is intended to empower decision makers to take action, and to prepare their territories to adapt, and hopefully thrive, under changing climatic conditions.

Yannick Glemarec
Director for Environmental Finance/UNDP-GEF Executive Coordinator

United Nations Development Programme
Bureau for Development Policy
Environment and Energy Group

Overview

- Purpose of Guidebook
- Target Audience
- UNDP Framework for Climate-Scenario Development
- Structure of the Report

Overview

Climate change is a pressing issue of our time that threatens global society. Its impacts cut across sectors and threaten the livelihoods and ecosystems of vulnerable communities across the world. It is challenging decision makers at all levels — international, regional, national, and sub-national — to prioritize this threat and develop creative, integrated solutions. These solutions must address both the urgent development issues that countries are facing and help respond to the risks of climatic change. Addressing these issues in tandem allows for cost-effective and holistic mitigation and adaptation approaches that are sensitive to the increasingly scarce financial resources available and the urgency of the issues in relation to human and economic prosperity.

> “Climate scenarios can provide important information about the possible future climate in a region. This information can be used to address the potential adverse impacts of climate change in a way that promotes low-emission climate-resilient development.”

As awareness increases, so does the need for capacity building and training. In many cases, communities are inhibited not by a lack of will, but by a lack of technical expertise and knowledge that prevents them from effectively planning and putting necessary initiatives and policies in place. The desire for positive change is there, but the ability lags behind. Therefore, the provision of guidance and transfer of know-how is critical as countries prepare to tackle and overcome the impacts of climate change. With the appropriate tools, decision makers are better equipped to integrate development and climate change, and produce effective risk management plans.

Climate scenarios can provide important information about the possible future climate in a region. This information can be used to address the potential adverse impacts of climate change in a way that promotes low-emission climate-resilient development. Yet predicting a region’s future climate — the average weather pattern over a period of time (e.g. 30 years) — is uncertain. There are multiple methods available to produce plausible scenarios; some provide only low-resolution (‘coarse’) results while others (e.g. downscaling techniques) result in high-resolution outputs.

Methods for climate-scenario development should be determined by the intended use of the scenarios and balanced against the constraints that decision makers face. Within the context of low-emission climate-resilient development strategies (LECRDS), climate scenarios may require relatively high spatial and temporal resolutions in order to adequately inform vulnerability, adaptation, and mitigation assessments, which play an important role in determining how to safeguard against and prosper in a changing climate. The level and nature of vulnerability to climate change — a region's susceptibility to the potential adverse effects of climate change (including changes in climate variability and extremes) — was discussed in a recent guidance document by the United Nations Development Programme (UNDP), *Mapping Climate Change Vulnerability and Impact Scenarios: A Guidebook for Sub-National Planners* (UNDP, 2010).

Building climate scenarios is not without its challenges. Choosing the right method for climate-scenario development can only be done after careful evaluation of the available approaches against the needs (application) and constraints (e.g. financial, computing, workforce, scientific, etc.) that project managers and their teams face. Teams should include a range of expertise to accomplish tasks such as data collection, computing, and input/result analysis. These abilities are often limited in developing regions where the need for such skills is greatest and financial resources most constrained.

UNDP is responding to the existing information gaps with the provision of step-by-step guidance toolkits and guidebooks. The framework presented in this guidebook aims to assist project managers and their teams with climate-scenario development to meet the needs of LECRDS and other assessments. This report is part of a suite of UNDP publications for decision makers that are available online at www.undp.org/energyandenvironment/climatestrategies.

Purpose of Guidebook

This guidance document is a new contribution to the UNDP series on low-emission climate-resilient development strategies. It aims to build decision makers' capacity to succeed in the following tasks:

- Assess needs and uses for climate-scenario development
- Identify constraints to climate-scenario development (e.g. financial, computing, workforce, scientific) and determine needs for climate-scenario development in light of constraints
- Evaluate existing approaches to generate a prospective range of climate scenarios against identified needs, and build a strong team
- Develop and Document Climate Scenarios

It offers project managers and their teams a framework for the development of a prospective range of climate scenarios.

Target Audience

The target audience for this guidebook is project managers and decision makers who are working with a team of scientific and technical experts and are seeking an understanding of how to manage development of climate scenarios for their regions. The guidebook aims to empower project managers and decision makers to engage in discussions on climate-scenario development, including involvement in science-based decisions on the availability, applicability, and robustness of various climate-scenario approaches. The report introduces steps that guide the reader through the process of climate-scenario development. Table 1 presents a list of additional resources, some more scientific in nature, for scenario development.

Table 1: Guidance documents on climate-scenario development

Title	Author
UNDP-UNEP-GEF* National Communication Support Programme	
Guidance on the Development of Regional Climate Scenarios for Application in Climate Change Vulnerability and Adaptation Assessment	Lu, 2006
Applying Climate Information for Adaptation Decision Making: A Guidance Resource Document	Lu, 2007
IPCC* Task Group on Data and Scenario Support for Impact and Climate Analysis	
Guidelines for Use of Climate Scenarios Developed from Regional Climate Model Experiments	Mearns et al., 2003
General Guidelines on the Use of Scenario Data for Climate Impacts and Adaptation Assessment, Version 2	Carter, 2007
Other	
Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections.	Knutti et al, 2010
A Framework for Assessing Uncertainties in Climate Change Impacts: Low-Flow Scenarios for the River Thames	Wilby et al, 2004

* United Nations Environment Programme (UNEP); Global Environment Facility (GEF); Intergovernmental Panel on Climate Change (IPCC)

UNDP Framework for Climate-Scenario Development

The UNDP framework for climate-scenario development is intended to guide project managers through the scenario development process, help them identify the reasons driving their scenario development (i.e. why), and clarify their climate-scenario needs (e.g. what, when, where). A critical part of this process is helping decision makers identify their constraints (e.g. financial, computing, workforce, scientific, etc.) and understand the interplay among them to better approach climate-scenario development, in particular with respect to resource allocation. This framework is presented in Figure 1.

Figure 1: UNDP framework for climate-scenario development to support low-emission climate-resilient development strategies

Evaluate the needs and uses for climate scenarios
(Figures 2 and 3)

Identify the regional constraints (i.e. financial, computing, workforce, and scientific constraints) to climate-scenario development
(Figures 4 and 5)

Select upper and lower limits to future greenhouse gas emissions to create an emissions-based prospective range of climate scenarios
(e.g. SRES A2 and B1 scenarios)

Coordinate discussions between project managers and scientific experts to establish a scientific approach to climate-scenario development
(Figures 6, 7, and 8 to determine resolution, downscaling techniques, uncertainty analyses, and model scenarios)

Oversee climate-scenario development and prepare documentation to provide guidance on interpretation and potential uses of scenarios
(include methods, tools, and data sources as well as assumptions and limitations)

In support of this capacity-building process, the framework addresses the role that uncertainties play in climate-scenario development. It stresses that project managers should ideally work together with a team of scientific and technical experts to manage these uncertainties, select appropriate scenario methods, and build a prospective range of scenarios that will inform investment strategies and facilitate transition to low-emission and climate-resilient development.

> “ It stresses that project managers should ideally work together with a team of scientific and technical experts to manage these uncertainties, select appropriate scenario methods, and build a prospective range of scenarios that will inform investment strategies and facilitate transition to low-emission and climate-resilient development. ”

The proposed framework also addresses shortcomings that are common to many efforts. For example, project managers overseeing climate-scenarios development typically have a limited background in climate science, and scientific experts, who are tasked with the production of climate scenarios, might not fully understand the project’s non-scientific constraints and end-user needs. When addressed through improved lines of communication, these shortcomings can strengthen the development process and results. The framework provides a platform that should foster clear and frequent dialogue between team members to share knowledge and optimize climate-scenario development.

Finally, the framework emphasizes the need to document the entire process of climate-scenario development to help project managers and their team members respond to questions that planners and decision makers might raise. This information can also help to inform subsequent climate analyses.

Summary of Key Steps

STEP 1

EVALUATE AND DETERMINE NEEDS FOR CLIMATE-SCENARIO DEVELOPMENT

STEP 2

IDENTIFY REGIONAL CONSTRAINTS AND DEVELOP A REALISTIC PLAN FOR CLIMATE-SCENARIO DEVELOPMENT

STEP 3

UNDERSTAND UNCERTAINTY TO BUILD A PROSPECTIVE RANGE OF CLIMATE SCENARIOS

STEP 4

DEVELOP AND DOCUMENT CLIMATE SCENARIOS

Structure of the Report

The Overview sets the context for climate-scenario development and emphasizes the importance of identifying needs and uses for climate scenarios as well as the constraints (e.g. financial, computing, workforce, scientific, etc.) that project managers and their team of experts should consider when selecting appropriate climate-scenario approach(es). It also outlines the proposed UNDP framework for climate-scenario development as part of low-emission climate-resilient development strategies.

Chapters 1-4 present step-by-step guidance for climate-scenario development following the proposed UNDP framework. In Chapter 1, the **first step** provides guidance on how to build a strong climate-scenario development team. It also offers insight on how to evaluate the needs and uses for climate-scenario development through a scoping exercise. Further, it provides an approach to identify constraints and form a realistic strategy for climate-scenario development given the constraints with which the team is faced. In Chapter 2, the **second step** involves using the information identified in the first step to assess what can realistically be done when developing climate scenarios as part of LECRDS and other assessments. In Chapter 3, the **third step** gives guidance on how to understand and manage the uncertainties associated with climate-scenario development in order to build a prospective range of climate scenarios. In Chapter 4, the **fourth step** provides an overview of the general procedure for climate-scenario development and the available methods for regional and local-level efforts. It also emphasizes the need to document the climate-scenario-development process in order to inform team members and derive and share lessons learned.

Chapter 5 summarizes the report and the Annex introduces regional case studies to illustrate the climate-scenario development process and interplay between constraints and selection of climate-scenario method(s).

A list of references is included at the end of this report to inform readers on the literature that was consulted during the writing of the publication, and on important information that readers should consider reviewing when preparing and undertaking the task of climate-scenario development.

Chapter 1

Preliminary Steps to Climate-Scenario Development

Evaluate and Determine Needs for Climate-Scenario Development (Step 1)

- Build a Crosscutting Team for Developing Climate Scenarios (Step 1.1)
- Determine Climate-Scenario Needs (Step 1.2)
- Assess Connections and Evaluate Climate-Scenario Needs (Step 1.3)
- Formulate a Plan and Identify Existing Resources (Step 1.4)

1

Evaluate and Determine Needs for Climate-Scenario Development

Introduction

Evaluating and determining the needs for climate-scenario development provides a strong foundation from which project managers and their team of experts can work to produce climate scenarios that are cost-effective and meet the needs of the identified end users. There are four main tasks involved in this step. The first task (Step 1.1) is to build a crosscutting team of experts to combine expertise and guide the climate-scenario-development project manager through a range of questions and issues raised in the preliminary stages and throughout the entire process. The second task (Step 1.2) is to determine the needs for developing climate scenarios through a scoping exercise. In this exercise, the experts ask key questions to determine the purpose and needs for climate-scenario development. The third task (Step 1.3) is to evaluate the different needs, and the last task (Step 1.4) is to formulate a climate-scenario development plan.

> “Regular team meetings are suggested to keep the lines of communication open, share information, and foster a transparent and well-documented process.”

1.1 Build a Crosscutting Team for Developing Climate Scenarios

The first step for building an effective, prospective range of scenarios is the creation of a strong, interdisciplinary team to plan and execute the task. In many cases, this responsibility falls on the project manager. It requires a thorough assessment of what types of skills/expertise are required to undertake scenario development, the level of resources (i.e. budget and other) required and available, and who is accessible and able to contribute to the process. Frequently, this thought exercise identifies constraints (e.g. financial, computing, workforce, scientific, etc.) that the project manager will manage throughout the planning and implementation stages to stay on target and meet project objectives.

Table 2: Summary of key climate-scenario-development team members

Who	What	When	Notes
Project manager	Team leader	Whole project cycle (Steps 1-4)	Conceptualizes climate-scenario development; manages the budget; interfaces with team members
Scientist	Expert	Whole project cycle (Steps 1-4)	Expert in climate-related sciences
Climate modeler	Expert	Whole project cycle with an emphasis on consultations during Steps 1 and 4	Expert in climate models; advises on Steps 1-4; conducts analyses to produce current climatology and future climate scenarios
End user (planner, policy maker, etc.)	User	**Preliminary stages:** Consult to determine what and how the scenario information will be used (Step 1) **Post-development:** Provide end user with results of exercise along with all documentation	Incorporates climate-scenario information into vulnerability, adaptation, and mitigation assessments

1.2 Determine Climate-Scenario Needs

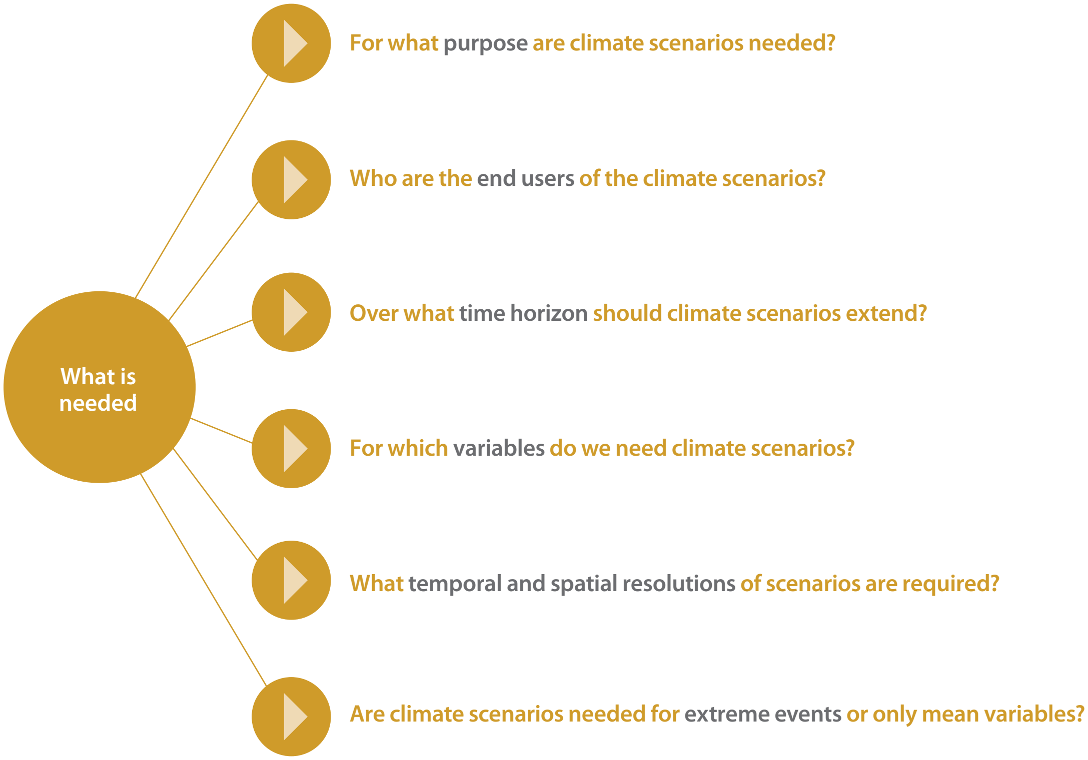
Once the team members are identified, they can begin to determine their needs (i.e. what) and organize their work (i.e. who, when) within the context of LECRDS or other assessments. An initial scoping exercise is essential to this process. Project managers can use the questions in Figure 2 to initiate discussions with team members regarding eventual climate-scenario needs. These discussions should involve the end users to ensure that their needs are met. During this exercise, the team should consider assigning roles to efficiently allocate tasks and resources. It is likely that the project manager will know the project budget in advance and will play an important role in distributing available funds. Regular team meetings are suggested to keep the lines of communication open, share information, and foster a transparent and well-documented process.

DEFINITION

Spatial and Temporal Resolutions

Spatial and temporal resolutions refer to the size of the area (e.g. 25 square kilometres [km^2], 2500 km^2) and time period (e.g. hourly, daily, monthly, seasonally) for which physical earth system processes are represented, respectively.

Figure 2: Key questions to determine the purpose and needs for climate-scenario development



Note: Adapted from Figure 5 (Lu, 2006).

> “Understanding the end-user’s needs can streamline the development of climate scenarios and render it more efficient and cost-effective.”

A discussion on the key questions addressed in Figure 2 below, and Tables 3 and 4 can be used as guides when determining climate-scenario needs. There is no set order in which to answer the questions.

Discussion of Key Questions to Determine Purpose and Needs for Climate-Scenario Development

Purpose: Determining the purpose for climate-scenario development is a critical starting point. Once the purpose is identified (i.e. reason for climate-scenario development), the project manager and team of experts have a foundation from which to build. For example, if climate scenarios are needed for an assessment of future water resources in a region, then the team should focus efforts to ensure that precipitation predictions are realistic.

End users: Identifying the end users (e.g. agricultural and water managers) and their needs helps the team to develop a scenario range that best fits their needs. Ideally, the purpose of the downscaling and the end-user needs would be aligned. As an example of end-user needs, farmers generally require climate information that includes the statistics of daily precipitation and temperature during the growing season (e.g. frequency, intensity, and duration of droughts). Understanding the end-user's needs can streamline the development of climate scenarios and render it more efficient and cost-effective.

Time horizon: Selecting future period (e.g. 2030s, 2050s, 2100s) for the climate scenarios is linked to the purpose and end-user needs.

Variables: Identifying the variables for climate scenario development helps to determine the type of data the team will need to collect.

Spatial and Temporal Resolution: Determining climate-scenario resolution (i.e. coarse or high resolution) is an important factor in building climate scenarios and is a central issue of this document. The needs for global, regional, and local level scenarios may require outputs at different levels of resolution. In general, regional and local scenarios tend to require a higher level of resolution to accurately inform decision makers. In the case of LECRDS, climate-change scenarios are used to identify vulnerability, mitigation, and adaptation options, as well as to assess financing needs for LECRDS implementation. The resolution for these purposes as well as other assessments varies depending on a number of main factors: (1) size of region; (2) physical geography, including a region's land cover, topography, and large-scale climate patterns; and (3) target application. These factors are addressed in Step 1.3.

Extreme Events: Determining whether climate scenarios should include mean climate variables or mean and extreme values of climate variables is a key decision, which influences the choice of scientific approach to the climate-scenario development. The main reason is because prediction skill is highly dependent on the target variable (e.g. minimum, maximum, and mean of daily or monthly temperature).

Table 3: **Suggested worksheet to determine the needs and purpose for climate scenarios**

Question	Response	Comment
What data sources are available?		
What are the key issues for accessing existing data?		
What is the skill of climate model predictions in the area of interest?		
How does the skill vary for different variables (e.g. temperature, precipitation, etc.)?		

> “… a discussion on the needs for climate-scenario development, in particular within the context of LECRDS, cannot take place without consideration of the size and physical geography of a region and scenario target application.”

Table 4: **Guidelines for determining climate-scenario-development needs**

Questions	Point person	Response
Purpose	Project manager (PM)	To assess future trends in climate as a tool for developing a low-emission climate-resistant development strategy, which includes adaptation and mitigation approaches
End users	PM	PM, Policy advisors Planners
Time horizon	PM/expert	2050s, 2100s, etc
Variables	Expert/PM	Temperature, precipitation
Resolution	Expert/PM	Temporal: hourly, daily, monthly, seasonally; Spatial: 5 kilometres (km), 50 km, 200 km
Extreme events	Expert	Maximum/minimum daily temperature and precipitation

1.3 Assess Connections and Evaluate Climate-Scenario Needs

After identifying the specific needs for climate-scenario development, it is important to assess how they are related to grasp what is required for scenario development. To do so, it is critical to recognize and understand that climate-scenario needs, including resolution, vary and depend on multiple factors. Therefore, a discussion on the needs for climate-scenario development, in particular within the context of LECRDS, cannot take place without consideration of the size and physical geography of a region and scenario target application.

Physical Characteristics and Target Application

Size of region and physical geography: The physical characteristics (i.e. size and geography) play a role in determining the needs for climate-scenario development. They are also linked to the question of climate-scenario resolution. The resolution for a given climate scenario varies by region depending on its size and physical geography: (1) land cover (forests, crop, urban, etc.) and watersheds; (2) topography and proximity to the ocean and surrounding mountains; and (3) large-scale climate patterns (e.g. El Niño-Southern Oscillation).

Target application (water resources, agriculture, etc.): Climate-scenario needs depend strongly on target application (e.g. agriculture, water, energy, disaster management, health, and biodiversity). The choice of climate variables (e.g. temperature, precipitation, etc.) and their resolution (e.g. daily, monthly, seasonal) for a given scenario is linked to the application of interest, just as the nature of a region's physical characteristics is dependent on the target application. Therefore, once the target application is identified, the project manager is better able to recommend the optimal set of climate-related variables for inclusion in the climate-scenario development (see Figure 3).

The link between target application and scenario resolution is also important. There may be a disconnect between what end users want in terms of resolution level and what project managers are able to provide with a given target application. In general, end users would like climate information at the highest possible spatial and temporal resolutions. Projects managers should strive to provide end users with climate scenarios that meet their resolutions needs. However, this is not always possible due to scientific and non-scientific constraints.

Figure 3: **Examples of target applications for climate scenarios**

Agriculture, forestry & ecosystems

- **Minimun data:** Temperature (T), precipitation (P)
- **Other data:** Solar radiation, humidity, wind, extremes
- **Data use:** Estimation of evapotranspiration and crop growth
- **Assessment foci:** Changes in vegetation productivity, drought/flood/fire frequency, livestock health, insect outbreaks

Water resources

- **Minimun data:** P
- **Other data:** T, extremes
- **Data use:** Estimation of river flows, evapotranspiration, groundwater recharge, etc.
- **Assessment foci:** Quantity and quality of water

Diaster management

- **Minimun data:** Extremes of T, P, and wind; sea level
- **Other data:** Pressure, radiation
- **Data use:** Estimation of extreme event effects
- **Assessment foci:** Susceptibility of infrastructure to extreme weather events, population vulnerability to flooding

Note: This figure illustrates climate scenario needs of various development-related applications. These applications were selected for illustrative purpose only.

DEFINITION

Spatial Resolution

Spatial resolution refers to the size of a grid cell at which a global climate models (GCMs) represents physical processes. For example, a climate model may have a resolution of 2°× 2°, which means that the dimensions of a grid cell will each be a few hundred kilometres (depending on latitude). A GCM's temperature predictions would therefore represent the *average temperature over this 2°× 2° area.*

1.4 Formulate a Plan and Identify Existing Resources

Once climate-scenario needs are identified and assessed, project managers and their team of experts can begin to formulate a development plan that will include the identification of existing information and tools on climate to assist with implementation; this should streamline the scenario-development process and optimize the utility of data collection and modeling efforts. To meet the needs of climate-scenario development, many teams will look to global climate models (GCMs) as a source for data on changes in climate.

Simulation data from GCMs (see Box 1) are readily available and provide information on changes in climate at a relatively low or coarse level of resolution. They are primarily used to understand the climate of the entire Earth system (macro level) rather than individual regions (micro level) of the Earth. The spatial resolution of a typical GCM is on the order of hundreds of kilometres, with predictions most readily accessible at a monthly time scale. Regional or local climate-scenario users, however, commonly need climate information at spatial resolutions of tens of kilometres or less, and at sub-monthly temporal resolutions (e.g. daily or hourly) depending on the application and the climatic and physical properties of their region. This difference in spatial resolution is about one order of magnitude. For temporal resolution, it is important to note that even if GCM predictions are available at higher resolutions (such as daily), these data should be interpreted with caution given uncertainty surrounding GCM skill in the prediction of daily variables.

STEP 1
EVALUATE AND DETERMINE NEEDS FOR CLIMATE-SCENARIO DEVELOPMENT
STEP 2
IDENTIFY REGIONAL CONSTRAINTS AND DEVELOP A REALISTIC PLAN FOR CLIMATE-SCENARIO DEVELOPMENT
STEP 3
UNDERSTAND UNCERTAINTY TO BUILD A PROSPECTIVE RANGE OF CLIMATE SCENARIOS
STEP 4
DEVELOP AND DOCUMENT CLIMATE SCENARIOS

Box 1: Global climate model basics

Project managers and decision makers can benefit from a general understanding of global climate models (GCMs), because they are the primary tools with which we understand and predict the future climate. A GCM is a tool used to simulate the numerous Earth-system processes that produce climate (McGuffie and Henderson-Sellers, 2005). These processes, including fluxes of moisture, heat, and momentum, are described using mathematical representations that are typically derived from basic physical laws. Detailed computer programs are then developed to solve numerous equations that describe the Earth system and are based on the fundamental principles of the conservation of mass, energy, and momentum.

A GCM, as with any model of a physical system, is a simplified representation where only the processes thought to be the most important are represented. The Earth's land, atmosphere, and oceans are represented in GCMs by dividing these components into grid cells. In each relevant grid cell, the interactions of the land, atmosphere, and oceans are simulated through calculation of air motion, radiation, heat transfer, and other variables. The simulation results then allow scientists to investigate, for example, global hydrological dynamics, the terrestrial and oceanic carbon cycles, cryospheric processes, and atmospheric chemistry for past, present, and future climates.

The current generation of GCMs is now able to capture many aspects of the Earth's current climate and its variability. At the same time, these models have limitations and therefore require further development and refinement. For example, it is difficult for GCMs to represent thunderstorms realistically because these storms are often very small relative to the size of a GCM grid cell. Further, scientists are only beginning to explore the role of other relevant local climate forcings, including those due to black carbon, solar variability, land-cover changes, and urban heat islands.

In light of the significant uncertainties in the climate system, we typically make use of the many available GCMs — each with differing representations of the Earth system — to produce model-based probabilistic assessments of future climate across a range of climate scenarios.

Please refer to McGuffie and Henderson-Sellers (2005) for a more detailed introduction to GCMs and their predictions.

Box 2: Distinction between GCM and high-resolution climate scenarios, a case for downscaling

The distinction between GCM and high-resolution climate scenarios is illustrated through consideration of GCM prediction of future temperature and precipitation for a period 30 years from the present. GCM climate predictions over this timeframe are average values over relatively large areas, which means that climate scenarios will have a coarse resolution. However, temperature and precipitation may vary significantly within these areas depending on characteristics such as topography, land cover, and proximity to the coast. If the spatial distribution of climate variables within these areas is important for informing a region's development strategies, then the use of a robust and credible downscaling technique to estimate temperature and precipitation at a finer resolution may be required.

The resolution mismatch between coarse GCM predictions and the high resolutions often needed for local and regional assessment has been the focus of extensive research in the scientific literature. This research has resulted in the development of numerous downscaling techniques to produce higher-resolution predictions when compared to typical GCM data. These techniques (e.g. spatial and analogue, dynamical and statistical downscaling, etc.) are available to address the scale mismatch (see Chapter 4). They vary in terms of their complexity, computational demand, and skill, and most use GCM outputs in their calculations. The resolution mismatch between GCM predictions and what is actually needed for some climate impact studies is demonstrated in Box 2.

Summary

Project managers, together with their teams, face the task of determining whether downscaling analyses are needed based on the scope of their assessment, target application, uncertainties, and scientific and non-scientific constraints. If the team determines that downscaling analyses are required, then they must decide how these analyses should be done. This chapter provided guidance on how to build a strong climate-scenario development team, offered insight on how to evaluate climate-scenario needs, and identified constraints to scenario development. The following chapter offers guidance on how to pinpoint and evaluate the regional constraints.

> “To meet the needs of climate-scenario development, many teams will look to global climate models (GCMs) as a source for data on changes in climate.”

Chapter 2

The Role of Regional Constraints in Climate-Scenario Development

Identify Regional Constraints and Develop a Realistic Plan for Climate-Scenario Development (Step 2)

- Evaluate Regional Constraints (Step 2.1)
- Identify Scientific Constraints (Step 2.2)
- Identify Non-Scientific Constraints (Step 2.3)
- Assess the Combination of Scientific and Non-Scientific Constraints (Step 2.4)

2

Identify Regional Constraints and Develop a Realistic Plan for Climate-Scenario Development

Introduction

In the previous chapter (Step 1), guidance for project managers and decision makers focused on undertaking a scoping exercise for evaluation of climate-scenario needs. Step 1 highlighted the need to assess the connections among climate-scenario needs (including resolution) and a region's physical characteristics, and the target application for the climate scenarios. This chapter (Step 2) emphasizes the need for open discussions between project managers and scientific experts on the constraints identified in Step 1 and further research to clarify the focus and regional context for climate scenarios. Working closely with experts will enhance the project manager's capacity to oversee development efforts and foster holistic consideration of both the scientific and non-scientific aspects of climate-scenario development. Both parties bring their own set of expertise to the dialogue, which complement each other and are essential to climate-scenario development.

> "Working closely with experts will enhance the project manager's capacity to oversee development efforts and foster holistic consideration of both the scientific and non-scientific aspects of climate-scenario development."

Project managers bring an understanding of financial and other non-scientific constraints to climate-scenario discussions, as well as their familiarity with both a region's characteristics and end users of climate scenarios.

Scientific experts provide scientifically based guidance on how climate-scenario development is influenced by a region's characteristics (size, topography, and climate influences), knowledge of baseline climate, and available models and techniques for climate-scenario generation.

Figure 4 presents fundamental questions on what can realistically be done in terms of climate-scenario development. This figure complements the questions provided in Figure 2 on the need for climate scenarios. These fundamental questions highlight basic issues of data availability, model skill, and constraints to climate-scenario development. Project managers can refer to Box 3 for additional information on data needs for climate-scenario development.

Box 3: **Key data for climate-scenario development**

Accessing and understanding key data for climate-scenario development is critical to the success of any scenario-development project. A first step for project managers to obtain this important information is to evaluate the availability of historical climate data for their region's baseline climate. They should consult with local scientists and other experts (if available) to analyse existing meteorological data (temperature, precipitation, wind, etc.) and other climate-related measurements. It is important to recognize that data quality is often an issue, especially for regions without significant scientific capacity. Also, the following aspects of their region's historical climate data should be considered.

- Number of stations
- Areal coverage of the data
- Length of the records
- Quality of the records

The quality control of observational data is typically a time consuming process; project managers should be aware of and plan for this. The availability of historical data is key to understanding future changes in climate. If, as with many developing countries, the regions are data-poor, then project managers may consider compiling data sets from other sources, including the following examples:

- WorldClim, interpolated climate surfaces for global land areas at a spatial resolution of 30 arc seconds (often referred to as 1-km spatial resolution). The climate variables available are monthly precipitation and mean, minimum, and maximum temperature: http://www.worldclim.org/.
- Global 50-yr (1948-2000) dataset of meteorological forcings derived by combining reanalysis with observations. Available at 2.0-degree and 1.0-degree spatial resolution and daily and 3-hourly temporal resolution: http://hydrology.princeton.edu/data.php.
- APHRODITE daily precipitation (0.5 and 0.25 degree) for portions of Asia: http://www.chikyu.ac.jp/precip/cgi-bin/aphrodite/script/aphrodite_cgi.cgi/register.
- Various products from the Tyndall Centre for Climate Change Research (http://www.tyndall.ac.uk), which include a 10-minute global monthly climatology for 1961 to 1990 and a 0.5° global time-series climate observations for 1901 to 2002. These products and others are available for download at http://www.cru.uea.ac.uk/cru/data/hrg/.

In addition to historical meteorological data, other types of data are also important for climate-scenario development. The properties of the land surface — including soil type, land cover type (e.g. forest, grassland, urban), and river networks — are key information that is needed for physically based models. Other data will depend on the nature of the vulnerability, adaptation, and mitigation assessment that will take place as part of the low-emission climate-resilient development (LECRDS) and may include population, energy, and emissions data.

Readers may also consult UNDP's recent publication, *Mapping Climate Change Vulnerability and Impact Scenarios: A Guidebook for Sub-National Planners* (UNDP, 2010) for further guidance.

STEP 1
EVALUATE AND DETERMINE NEEDS FOR CLIMATE-SCENARIO DEVELOPMENT

STEP 2
IDENTIFY REGIONAL CONSTRAINTS AND DEVELOP A REALISTIC PLAN FOR CLIMATE-SCENARIO DEVELOPMENT

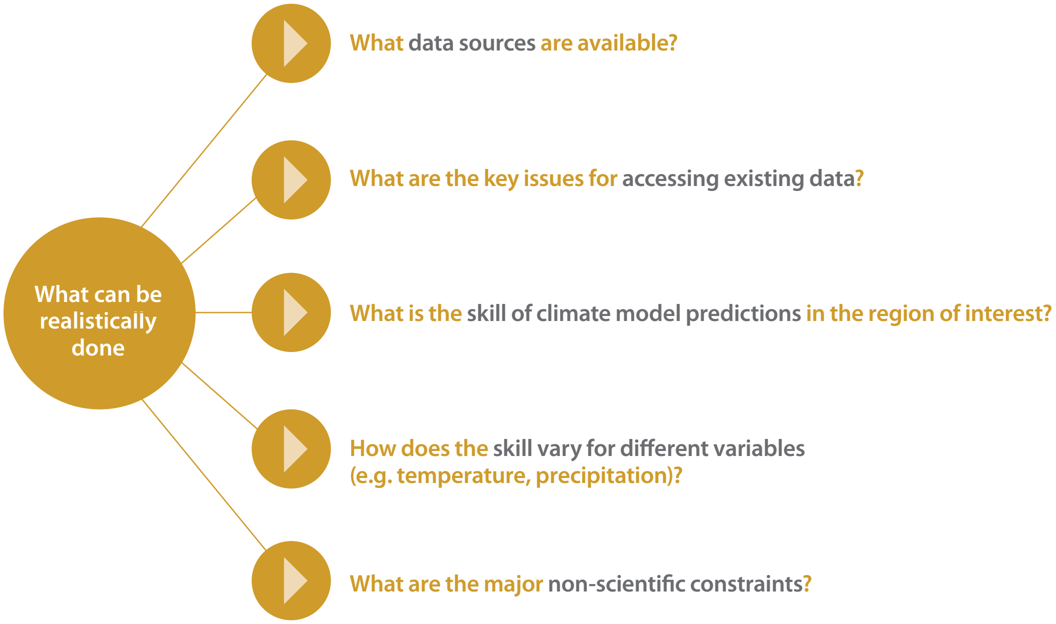
STEP 3
UNDERSTAND UNCERTAINTY TO BUILD A PROSPECTIVE RANGE OF CLIMATE SCENARIOS

STEP 4
DEVELOP AND DOCUMENT CLIMATE SCENARIOS

2.1 Evaluate Regional Constraints

Similar to the scoping exercise in Step 1, this step provides project managers and their team of experts with an opportunity to evaluate what level of effort and output is realistic based on a thorough analysis of basic issues of data availability, model skill, and constraints to climate-scenario development. The set of questions put forth in Figure 4 provides a format for this process.

Figure 4: Key questions to determine a realistic plan of action for LECRDS climate-scenario development



Note: This figure suggests a list of fundamental questions to assess *what can realistically be done* when developing climate scenarios as part of LECRDS and other assessments. Adapted from Figure 5 (Lu, 2006).

> “The properties of the land surface — including soil type, land cover type (e.g. forest, grassland, urban), and river networks — are key information that is needed for physically based models.”

Table 5: Suggested worksheet to determine the best climate-scenario-development approach

Question	Response	Comment
What data sources are available?		
What are the key issues for accessing existing data?		
What is the skill of climate model predictions in the area of interest?		
How does the skill vary for different variables (e.g. temperature, precipitation, etc.)?		
What are the major non-scientific constraints?		

2.2 Identify Scientific Constraints

As previously highlighted, some of the main science-related issues that project managers and scientific experts should consider when determining what can be done are listed below.

- Availability and resolution of observational data
- Size of region
- Time horizon (future periods of interest)
- Target application

A region's physical geography, which includes its geomorphology, hydrology, ecology, and climatology, is also a key factor to consider. It will have a strong influence on climate-scenario development, especially in relation to climate-scenario resolution.

The relationship between physical geography and climate-scenario resolution is presented qualitatively in Figure 5. This figure provides a visual aide to project managers and their teams to better understand the link between the physical geography of a given area and the optimal level (i.e. coarse or high) of resolution for climate-scenario development. In other words, it provides guidance on how to match climate-scenario resolution with the unique physical characteristics of an area.

STEP 1
EVALUATE AND DETERMINE NEEDS FOR CLIMATE-SCENARIO DEVELOPMENT

STEP 2
IDENTIFY REGIONAL CONSTRAINTS AND DEVELOP A REALISTIC PLAN FOR CLIMATE-SCENARIO DEVELOPMENT

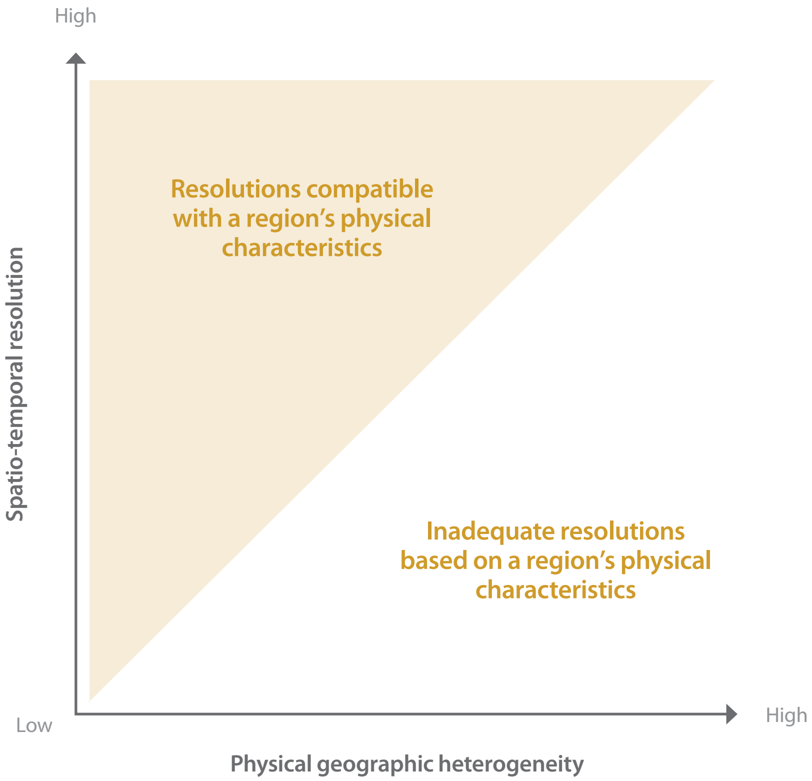
STEP 3
UNDERSTAND UNCERTAINTY TO BUILD A PROSPECTIVE RANGE OF CLIMATE SCENARIOS

STEP 4
DEVELOP AND DOCUMENT CLIMATE SCENARIOS

In Figure 5, the spatio-temporal resolutions compatible with an area's physical characteristics are identified relative to the heterogeneity in its physical geography. For simplicity, an area's physical geography is characterized in terms of spatial heterogeneity, recognizing that higher resolution scenarios are typically needed as heterogeneity increases. Two domains are identified in this figure, one where climate-scenario resolutions are compatible with a region's physical characteristics (shaded area) and another where resolutions are inadequate (white area). Although this figure provides only a basic qualitative understanding of the relationship, it is useful for framing discussions on the scientific aspects of climate-scenario development between project managers and scientific experts.

> “Discussions on the scientific and non-scientific constraints to climate-scenario development can be framed using Figure 6.”

Figure 5: Influence of the physical geography (i.e. geomorphology, hydrology, ecology, and climatology) on spatio-temporal resolution of climate scenarios



Note: A region's physical geography is characterized in terms of spatial heterogeneity, where higher resolution scenarios are needed as heterogeneity increases.

2.3 Identify Non-Scientific Constraints

In addition to the influence of scientific constraints (e.g. spatio-temporal resolution) on climate-scenario development, there are multiple non-scientific issues discussed in Step 1 (data constraints, financial, workforce, etc.) that will also have an influence. Project managers should guide discussions with their team of experts so that a variety of approaches — consistent with a project's available resources — are evaluated.

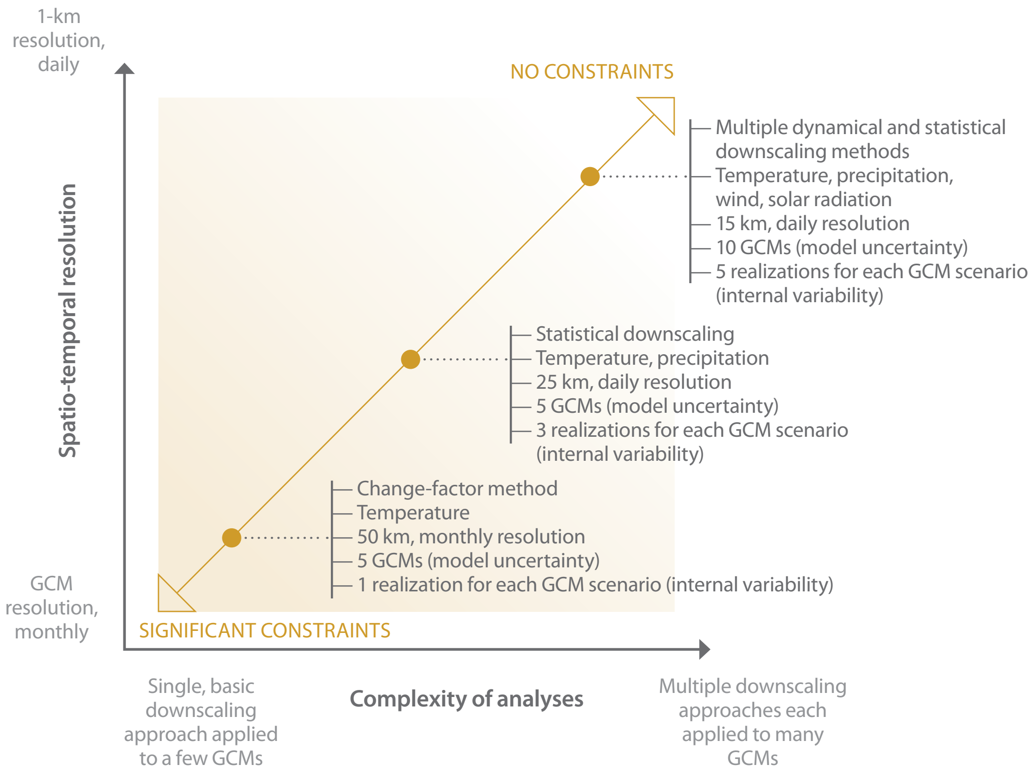
2.4 Assess the Combination of Scientific and Non-Scientific Constraints

Figure 6 schematically presents the relationship among the complexity of analyses, spatio-temporal resolution, and non-scientific constraints to climate-scenario development. Here, 'complexity of analyses' refers to the characteristics of the approach for climate-scenario development. For example, an approach with relatively low complexity would be an analysis where climate scenarios are obtained with a single GCM for one realization only (i.e. not accounting for uncertainty due to internal climate variability — see Chapter 3). Conversely, an analysis with high complexity would involve output from many GCMs with multiple realizations for each GCM, where several downscaling techniques are employed. With regard to spatio-temporal resolution, a low-resolution case would have scenarios with a similar resolution to GCM output (i.e. monthly output for 2°× 2° grid cells), and a very high-resolution case might have climate scenarios at a daily, 1-km resolution.

Discussions on the scientific and non-scientific constraints to climate-scenario development can be framed using Figure 6. The figure qualitatively illustrates that the potential complexity of analyses and spatio-temporal resolution will depend on a project's non-scientific (data, financial, computing or workforce) constraints. As these constraints increase, the potential complexity and resolution of climate analyses will generally diminish.

Three hypothetical examples are highlighted in Figure 6: (1) no constraints; (2) medium constraints; and (3) significant restraints. Located within the figure's resolution-complexity space, all three constraints are paired with an appropriate climate-scenario-development method that matches the constraint level presented in each case. This shows the interplay between non-scientific constraints and the choice of spatio-temporal resolution, as well as the complexity of the decision-making and analyses processes. In the annex to this report, three case studies on climate-scenario development are presented to illustrate the relevance of Figure 6 to real-world problems.

Figure 6: **Interplay among non-scientific (data, financial, computing or workforce) constraints, complexity of analyses, and spatio-temporal resolution for climate-scenario development**



“An optimal approach for climate-scenario development can only be reached through iterative discussions on scientific and non-scientific constraints, as illustrated in Figures 5 and 6, which stem from holistic, ongoing dialogue between project managers and experts.”

Summary

An optimal approach for climate-scenario development can only be reached through iterative discussions on scientific and non-scientific constraints, as illustrated in Figures 5 and 6, which stem from holistic, ongoing dialogue between project managers and experts. The dialogues should result in the creation of a set of plausible climate scenarios at specific spatial and temporal resolutions that best meet the end-users’ needs, while addressing the real constraints faced with scenario development. A clear description of the assumptions and uncertainties associated with the range predictions should accompany any climate scenario.

The information presented in Chapters 1 and 2 empowers climate-scenario-development teams to make full use of the content offered in later parts of the report. Before choosing a downscaling technique, it is important for climate-scenario-development teams to understand the uncertainties that are inherent to climate-scenario development and how they relate to the different downscaling approaches. This issue is the focus of the next chapter.

Chapter 3

Uncertainty and Climate-Scenario Development

Understand Uncertainty to Build a Prospective Range of Climate Scenarios (Step 3)

- Review Main Sources of Uncertainty in Model Predictions (Step 3.1)
- Select Emissions Scenarios to Create a Prospective Range of Climate Scenarios (Step 3.2)
- Consider Other Uncertainties When Building a Prospective Range of Climate Scenarios (Step 3.3)
- Make Informed Decisions Despite Uncertainties In Climate Scenarios (Step 3.4)

3

Understand Uncertainty to Build a Prospective Range of Climate Scenarios

Introduction

Understanding the uncertainties associated with developing climate scenarios is an important part of the development process. It is valuable to project managers and their team of experts as well as the scenario end users. Climate-scenario-development teams benefit from this knowledge because it allows them to make more informed decisions on which model and technique to use to build the most robust and effective prospective range of climate scenarios to pursue LECRDS and other assessments. Climate-scenario-development teams should consult with scientific experts to discuss an approach to quantify uncertainty in climate scenarios to evaluate method selection and inform end users. The confidence or reliability associated with climate scenarios is key information, especially for end users of the data. Therefore, communicating information on uncertainties to end users will allow them to develop more robust climate information for their vulnerability and impact studies.

> “It is helpful for project managers and their teams to understand the range of uncertainties associated with climate-scenario development before they chose their approach (i.e. model, downscaling technique, etc.).”

This chapter will review the main sources of uncertainty that arise during climate-scenario development and then discuss the interplay between the complexity of climate-scenario analyses (including uncertainty assessment) and climate-scenario resolution. It will also discuss how decision makers can use climate scenarios to make informed decisions despite the uncertainties associated with climate models (uncertainty in greenhouse gas [GHG] emissions, model response uncertainty, and internal variability of the climate system). It is helpful for project managers and their teams to understand the range of uncertainties associated with climate-scenario development before they chose their approach (i.e. model, downscaling technique, etc.). The content and figures presented in this chapter seek to illustrate how the different combinations of uncertainties relate to the complexity of scenario analyses and choices of models and techniques for scenario development.

3.1 Review Main Sources of Uncertainties in Model Predictions

In general, the uncertainties in climate-model predictions of future climate arise from three distinct sources: uncertainty in future GHG emissions, model response uncertainty, and internal variability of the climate system.

Uncertainty in future GHG emissions: This source of uncertainty is likely most familiar to project managers and decision makers. Uncertainty in future GHG emissions is due to the uncertainties in key assumptions about the relationships among future population, socio-economic development, and technical changes as they affect GHG emissions.

Model response uncertainty: Models can predict different changes in climate for the same forcings; these inter-model differences are due to varying mathematical representations of the Earth system.

Internal variability of the climate system: This uncertainty refers to the natural fluctuations in climate that occur apart from any radiative forcings of the Earth system. The fluctuations are important for project managers, as pointed out by Hawkins and Sutton (2009), because they can potentially reverse long-term climate trends — reversals that can last a decade or so.

To clarify these sources of uncertainty for project managers and decision makers, it is useful to identify where each source arises when developing climate scenarios. Figure 7 is provided as a visual aide to show the main components of climate-scenario development (GHG, global climate change, regional detail, impacts) along with their associated uncertainty sources (e.g. Mearns et al., 2003; Quintana Seguì et al., 2009).

DEFINITION

Radiative Forcing

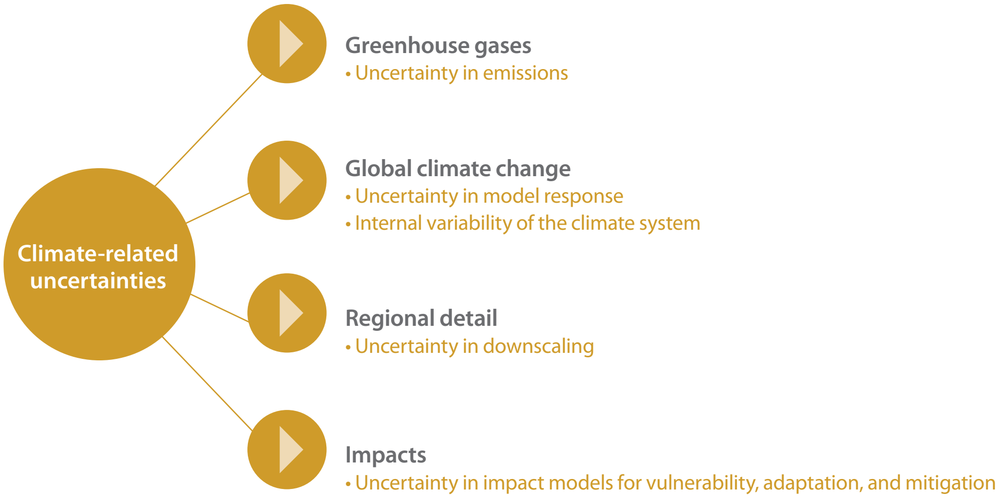
Radiative forcing refers to the influence a factor has in changing the balance of incoming and outgoing energy in the Earth system.

DEFINITION

SRES A2 Scenario

The A2 storyline describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

Figure 7: Major sources of uncertainty relevant when developing climate scenarios



Note: Based on the 'uncertainty cascade' concept of Mearns et al. (2003) and Figure 2 of Lu (2007). This figure presents the major sources of uncertainty that are relevant when developing climate scenarios. Project managers should assess each of these uncertainty sources and manage them through development of a *prospective range of climate scenarios.*

> “A recommended first task in the construction of a prospective range of climate scenarios is the consideration of both high and low GHG emission scenarios.”

Discussion of the Major Sources of Uncertainty Relevant when Developing Climate Scenarios

Greenhouse Gases: A first uncertainty source in Figure 7 involves selection of GHG-emission scenarios. Given that the precise magnitude and timing of future emissions is unknown, project managers must recognize that GHG emissions are a major source of uncertainty.

Global Climate Change: The next uncertainty source arises when predicting global climate change. This source occurs because of differences in model response, as well as internal variability of the climate system.

Regional Detail and Impact Model: Two additional uncertainty sources are downscaling and impact-model uncertainty. Downscaling uncertainty manifests itself when multiple downscaling techniques — applied to the same GCM data — produce different climate predictions. This uncertainty has been demonstrated in scientific studies that compare multiple downscaling techniques (e.g. Wilby and Harris, 2006), although it is poorly understood at present. Impact-model uncertainty occurs due to incomplete knowledge of how climate change may affect various sectors of society. Of these two sources, downscaling uncertainty is the most relevant to this guidebook, although project managers should be aware that end users of the climate scenarios could ultimately have to deal with impact-model uncertainty, especially for low-emission climate-resilient development strategies.

While these various sources of uncertainty appear — and are in fact daunting — the proposed framework that will allow project managers and scientific experts to manage the uncertainties that arise during climate-scenario development. The goal is to produce a prospective range of climate scenarios that will encompass the likely range of future climate conditions for an area. In the following steps, we discuss how project managers and scientific experts should deal with these sources of uncertainty when developing climate scenarios.

3.2 Select Emissions Scenarios to Create a Prospective Range of Climate Scenarios

A recommended first task in the construction of a prospective range of climate scenarios is the consideration of both high and low GHG emission scenarios. This approach establishes an initial set of bounds on our climate scenarios and should streamline discussions between project managers and scientific experts on emissions uncertainty. An alternative approach would be to consider a 'middle-of-the-road' scenario, but it is unclear whether such a scenario could be realistically identified. This middle-of-the-road approach might also prevent the establishment of a climate-scenario range to address the emissions uncertainties, which is the intent of this step.

The most accessible scenarios on GHG emissions are from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000). These scenarios were used in the IPCC Fourth Assessment Report (AR4) analyses. While the SRES scenarios are currently the most widely used emissions scenarios, efforts are underway to replace these scenarios — an important effort given that these scenarios are now a decade old.

If project managers are using AR4 climate model data, then they may build their range by considering the SRES A2 and B1 scenarios. These scenarios correspond to a range of approximately 540 to 970 parts per million of carbon dioxide in the atmosphere in 2100 (IPCC, 2001). Other SRES scenarios may be substituted depending on the details of a specific project.

A new approach to deal with uncertainty in GHG emissions, termed Representative Concentration Pathways (RCPs), was introduced as part of the IPCC Fifth Assessment Report (AR5). Although description of this approach is beyond the scope of this guidance material, we mention it here because it is relevant for AR5-based analyses. For further discussions on RCPs, please refer to Moss et al. (2010). We note that RCPs — although not forecasts or boundaries for potential emissions — may (like SRES scenarios) possibly be used to develop a prospective range of climate scenarios because they represent the radiative-forcing range in the scientific literature (at the time of their selection). Considering that the AR5 is an ongoing report, project managers and scientific experts should examine up-to-date developments when selecting their bounding emissions-related scenarios.

3.3 Consider Other Uncertainties When Building a Prospective Range of Climate Scenarios

Unlike the simple approach for emissions uncertainty in the previous step, it is less straightforward to deal with the other uncertainty sources. It is generally important to account for all uncertainty sources (Quintana Seguì et al., 2009), but the question of how to account for these uncertainties cannot be separated from other fundamental decisions (e.g. selection of scenario resolution and downscaling techniques). These other decisions are themselves controlled by non-scientific constraints to climate-scenario development. To illustrate the challenge that project managers and scientific experts face in accounting for uncertainty sources, two hypothetical cases for climate-scenario development are considered in Box 4 and illustrated in Figures 8a and 8b.

> “It is generally important to account for all uncertainty sources (Quintana Seguì et al., 2009), but the question of how to account for these uncertainties cannot be separated from other fundamental decisions (e.g. selection of scenario resolution and downscaling –techniques).”

Box 4: Hypothetical cases for climate-scenario development

Using Figure 6 as a basis, two extreme cases for climate-scenario development are considered. The first case is a situation where climate-scenario development is not limited by any data, financial, computing, or workforce constraints. The second case is where climate-scenario development is substantially constrained by data, financial, computing and workforce limitations. Figures 8a and 8b present the range of analysis complexity and spatio-temporal resolution that are potentially consistent with these non-limited and limited cases, respectively.

Although project managers might expect straightforward climate-scenario development in the unconstrained case (Figure 8a), substantial discussions are still needed to identify an optimal balance of analysis complexity and scenario resolution. In Figure 8a, the shaded area indicates the ‘best’ options for climate-scenario development. Clearly, there is no single, optimal approach for climate scenario development, even for this unconstrained case. Project managers will always have multiple options — especially to account for uncertainty sources — that must be discussed with scientific experts.

For the substantial-constraint scenario (Figure 8b), project managers will be limited to coarse-resolution scenarios and basic downscaling techniques. Certainly, one of the most critical limitations is related to the availability of observational data. Without observational data, most downscaling techniques cannot be used, such that climate-scenario development is likely limited to coarse GCM outputs. The GCM output could still be analyzed with hypothetically significant constraints, because the data are readily accessible in the IPCC AR4 archives. In fact, one potentially useful option in this case would be to use the predictions already prepared for various regions by the IPCC (see Christensen et al., 2007).

DEFINITION

SRES B1 Scenario

The B1 storyline describes a convergent world with a global population that peaks in mid-century and declines thereafter. It assumes rapid changes in economic structures toward a service and information economy. This change leads to reductions in material intensity as well as the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity. Additional climate initiatives, however, are not included.

Figure 8: **Relationship between analysis complexity and resolution for two hypothetical scenarios of data, financial, computing, and workforce constraints to climate-scenario development**

Figure 8a: No constraints

Climate-scenario development is not constrained by any data, financial, computing, and workforce limitations.

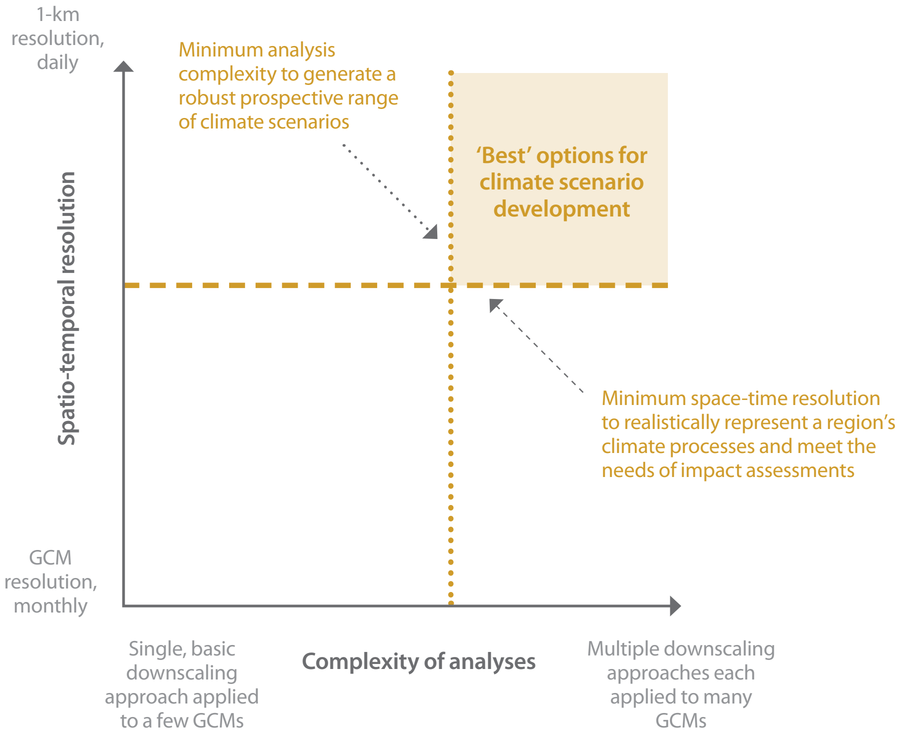
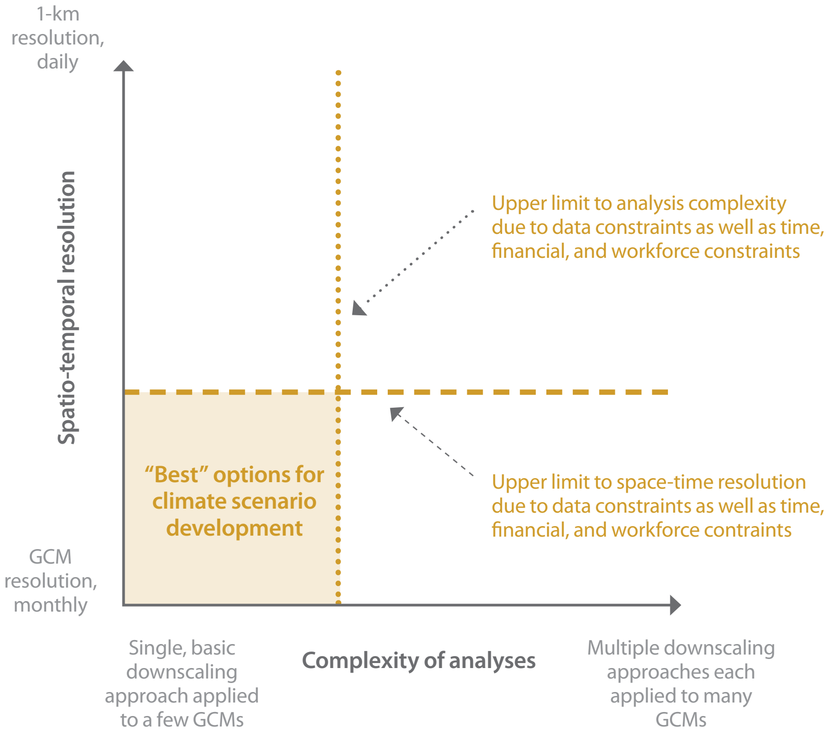


Figure 8b: Substantial constraints

Climate-scenario development is substantially constrained by data, financial, computing, and workforce limitations.



3.4 Make Informed Decisions Despite Uncertainties in Climate Scenarios

The various sources of uncertainty are a primary reason why the options for climate-scenario development are not unique, even for the hypothetical cases presented in Box 4. Project managers will often have many options in how they account for uncertainties. Unfortunately, there is no established methodology in scientific literature to dictate how extensive uncertainty analyses should be. In fact, the majority of scientific efforts for high-resolution climate-scenario development do not fully account for all sources of uncertainty. Ultimately, project managers and their teams should base their decisions on the factors identified as a result of Steps 1 and 2 of this guidebook and a review of the uncertainties addressed in this chapter. Open and ongoing discussions between team members will assist all parties in effectively managing uncertainties and guiding scenario development.

Summary

In the context of policy design, the uncertainty-based discussions are critical because they clarify the best available climate-scenario information to project managers and decision makers. These efforts will allow the characterization and, to the extent possible, quantification of scientific uncertainties. With this additional information, the potential implications of the uncertainties for the outcomes of concern to the decision makers will be clear (e.g. McMichael et al., 2003).

> “Open and ongoing discussions between team members will assist all parties in effectively managing uncertainties and guiding scenario development.”

The challenge of making decisions in the presence of uncertainty is not unique to climate change; policy decisions are made every day even with uncertainties for a wide range of issues. Policy makers can, in fact, take action in anticipation of climate change even though uncertainties exist. McMichael et al. (2003) point out that many different criteria exist for decision making on climate-related policy, including the precautionary principle and benefit-cost analysis. While discussion of these approaches is beyond the scope of this guidebook, the key point is that an understanding of uncertainty and its various sources is essential; otherwise, the developed climate scenarios may be misleading. Ultimately, climate scenarios should enable project managers and decision makers to make informed decisions about the likely impacts of climate change.

In Chapter 4, this guidebook provides information on the range of downscaling techniques available to help project managers and their team of experts make informed decisions on technique selection. Because climate modeling — both global and regional — are active areas of research, project managers should exercise care when using and analysing results from any downscaling effort.

Chapter 4

Methods for Climate-Scenario Development

Develop and Document Climate Scenarios (Step 4)

- Review General Procedures For Climate-Scenario Development (Step 4.1)
- Choose a Climate-Change Model (Step 4.2)
- Document Climate-Scenario-Development Process (Step 4.3)

4

Develop and Document Climate Scenarios

Introduction

In the previous chapters, guidance for project managers and decision makers focused on how to identify needs and regional constraints, define a realistic strategy based on existing constraints, and manage the uncertainties of climate-scenario development. This chapter provides an overview of the general procedures for climate-scenario development and the main options available for development of high-resolution climate scenarios. It is offered to assist project managers in their interactions with scientific experts as they consider potential alternatives for climate-scenario development. The information presented is not intended to be a complete technical description of downscaling techniques. Rather, the goal is to provide the reader with an introduction to the main downscaling techniques h/she may decide to use during the development of climate scenarios. Downscaling techniques can provide details at higher spatio-temporal resolutions than global climate models, which may be useful to planners at the local and regional level. This chapter seeks to empower project managers to interact with climate experts while developing climate scenarios. More scientific details on downscaling techniques are available and referenced in Table 1.

> “Downscaling techniques can provide details at higher spatio-temporal resolutions than global climate models, which may be useful to planners at the local and regional level.”

4.1 Review General Procedures for Climate-Scenario Development

A first step in producing climate change scenarios is reviewing and understanding the general procedures for climate-scenario development. A summary of the procedures is offered below. It sets the context for downscaling to produce high-resolution climate scenarios and provides project managers with a clear understanding of the climate-scenario-development process (e.g. Diaz-Nieto and Wilby, 2005; Lu, 2006).

Climate-Scenario Development Procedure

Procedure 1: Establish a *baseline climate* over a given time period for a specific geographic region (referred to as the observational baseline climate). This should be developed at spatial and temporal resolutions that provide sufficient information for developing future climate scenarios. That is, if high-resolution climate scenarios are needed, then the baseline climate data should be of comparable resolution.

Procedure 2: Compute a *model-based change* between present and future climate using GCMs (or some other method).

Procedure 3: Construct a *future climate scenario* by adding the model-based change to the baseline climate.

4.2 Choose a Climate-Change Model

The general procedure outlined in Step 4.1 specifies that climate models are typically used for information on climate changes. Although GCMs are the primary sources for climate-change scenarios, they are not the only option. More basic approaches for climate-change predictions exist — the temporal or spatial analogue approach and the arbitrary approach — that project managers and decision makers could also consider as scenario-development options. A brief discussion of analogue and arbitrary-change approaches is provided in the Tables 6 and 7 before the more complex downscaling techniques are introduced. This format is used to present the information in a clear and concise manner, highlight the pros and cons to each approach, and provide a working example to illustrate the basic technique.

Analogue and Arbitrary Approach

With regard to climate-scenario resolution, the analogue and arbitrary-change approaches described below are different from GCM-based scenarios. The resolution for these approaches will depend on the observational data used to construct the climate baseline. Therefore, if the observational data and the resulting baseline climate available are coarse, project managers might consider a downscaling technique over one of the basic approaches to develop a high-resolution baseline climate. The discussions of downscaling techniques that follow in this chapter are limited to their use with GCM-based scenarios of climate change.

STEP 1
EVALUATE AND DETERMINE NEEDS FOR CLIMATE-SCENARIO DEVELOPMENT

STEP 2
IDENTIFY REGIONAL CONSTRAINTS AND DEVELOP A REALISTIC PLAN FOR CLIMATE-SCENARIO DEVELOPMENT

STEP 3
UNDERSTAND UNCERTAINTY TO BUILD A PROSPECTIVE RANGE OF CLIMATE SCENARIOS

STEP 4
DEVELOP AND DOCUMENT CLIMATE SCENARIOS

Table 6: The temporal and spatial analogue approach

The temporal or spatial analogue approach involves the construction of temporal or spatial analogues using historic climate data. The data used as temporal and spatial analogues is either from the past or from another location (Wilby et al., 2004).	
Pros	**Cons**
- Relatively easy access to historic climate data - Straightforward analyses related to climate changes	- Difficulty finding data from another location that is similar enough to the area in question - Analogues might not represent future climate realistically - Few climate variables typically available
Example	
Predicting summer temperature in a given location: Using temporal or spatial approach, data on temperature in a given location for the summer months over a specific period of time (e.g. last year) would be obtained and assumptions would be made on the future based on past conditions. This approach assumes, for example, that if a past year's summer in a given location was particularly warm, and this type of summer season is expected to become more common in the future (e.g. according to observational or model-based trends), then the frequency of such an event can be increased as an approximation of future climate conditions.	
Comment	
This approach may not provide the most accurate results. Project managers and their teams should discuss whether a higher degree of confidence could be placed in climate scenarios developed with more detailed downscaling techniques. They should also then consider the costs and benefits of more detailed analyses relative to this approach.	

DEFINITION

Temporal and Spatial Analogues

Radiative forcing refers to the influence a factor has in changing the balance of incoming and outgoing energy in the Earth system.

> "More basic approaches for climate-change predictions exist — the temporal or spatial analogue approach and the arbitrary approach — that project managers and decision makers could also consider as scenario-development options."

Table 7: The arbitrary change approach

The arbitrary change approach assigns random changes, at regular intervals, to various variables (e.g. temperature and precipitation) of the established baseline climate, bypassing the need for use of more complicated climate scenario techniques (e.g. Lu, 2006).

Pros	Cons
● Minimal effort is invested in development of climate scenarios (i.e. GCM output, downscaling techniques, and uncertainty analyses) ● Frees up time to focus on modeling and assessing a region's vulnerability, adaptation, and mitigation strategies, which are important for LECRDS	● The baseline climate changes are arbitrary; probabilities cannot be assigned to the various assumed climate changes

Example

Climate scenario development for agricultural sector: If the climate-scenario end user is concerned with the agricultural sector, then temperature increases of 1°C, 2°C, and 3°C along with precipitation changes of ±5% and ±10% could be applied to a crop model. This approach is essentially a sensitivity analysis to understand the response (including identification of nonlinearities and critical thresholds) of a specific sector to incremental changes in climate.

Comment

This approach may not provide the most accurate results. Project managers and their teams should discuss whether a higher degree of confidence could be placed in climate scenarios developed with more detailed downscaling techniques. They should also then consider the costs and benefits of more detailed analyses relative to this approach.

Downscaling techniques for high-resolution climate scenarios

Downscaling techniques are generally used to combine coarse-scale climate information with other higher resolution data to produce predictions of climate variables at higher resolutions. Most techniques combine observational, high-resolution data (e.g. historical climate observations, topography) with climate-model predictions. There are three main categories of downscaling techniques.

- Basic
- Dynamical
- Statistical

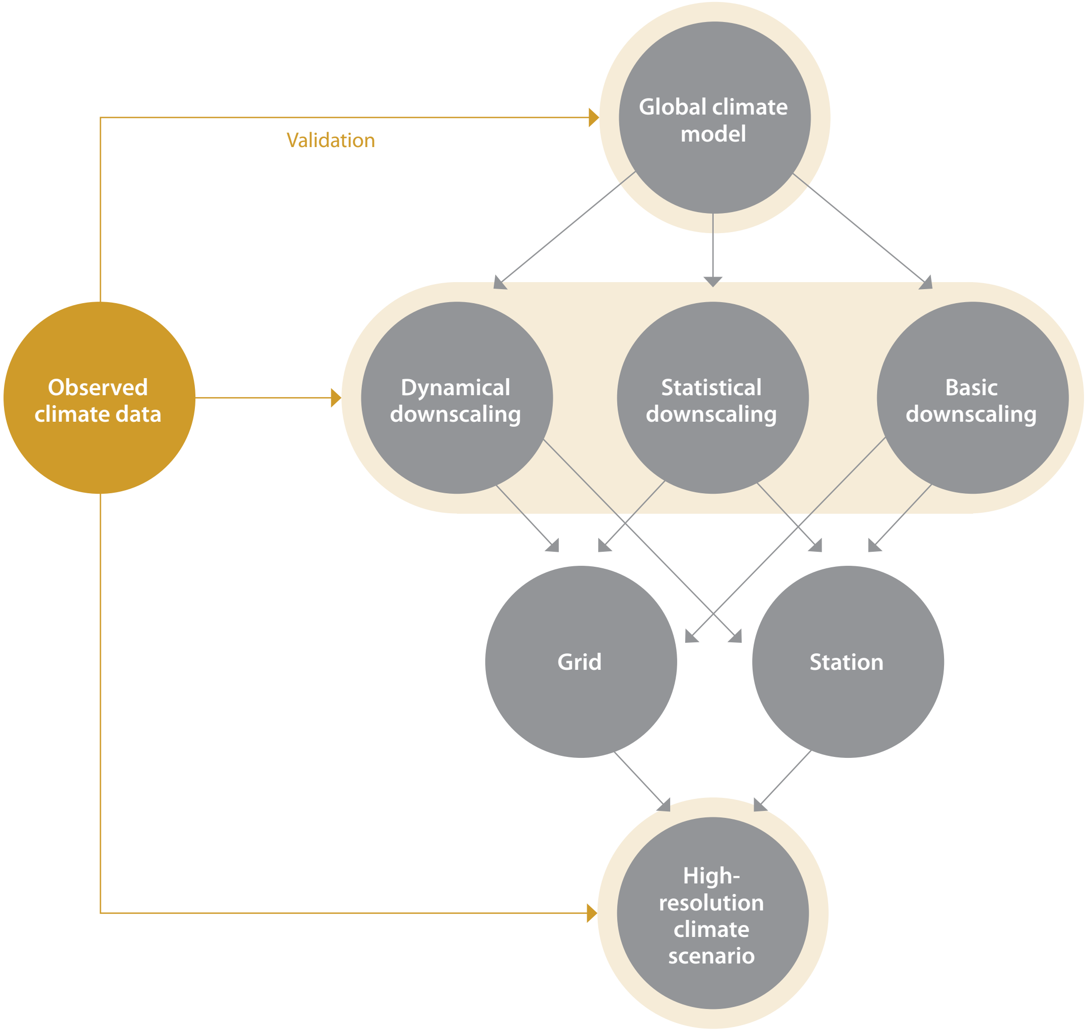
Figure 9 presents how these three categories relate to GCM output and observational data as part of the climate-scenario-development process. As shown, observation-based data is pivotal to all downscaling techniques.

DEFINITION

Arbitrary-Change Approach

The arbitrary-change approach is a basic approach to climate-change predictions that assigns specified changes, at regular intervals, to various variables (e.g. temperature and precipitation) of the established baseline climate, bypassing the need for use of more complicated climate scenario techniques.

Figure 9: **Schematic diagram of the three main downscaling techniques as part of the process of climate-scenario development**



Note: Based on Figure 1 of Ziervogel and Zermoglio (2009).

> Downscaling techniques are generally used to combine coarse-scale climate information with other higher resolution data to produce predictions of climate variables at higher resolutions.

DEFINITION

Basic Downscaling Approaches

There are several basic downscaling approaches. Two popular methods are the 'change-factor' and 'unintelligent' methods. The change-factor method directly applies GCM-derived changes in climate to a baseline climatology. The 'unintelligent' method involves simple spatial interpolation between the center points of GCM grid cells to obtain estimates at the desired intermediate points corresponding to those in a higher-resolution baseline climatology.

Basic downscaling approaches

The three categories of techniques can be combined to improve and optimize climate-scenario development (Quintana Seguì et al., 2009). For clarity of presentation, however, they are presented individually.

There are several basic downscaling approaches available to project managers and their team of scientific and technical experts. A very popular method to obtain higher spatial resolution for predictions of climate variables is known as the 'change-factor' or 'delta' method (Wilby et al., 2004).

CHANGE-FACTOR METHOD

The change-factor method directly applies GCM-derived changes in climate to baseline climate data as described in the general procedures for climate-scenario development in Step 4.1. In the context of downscaling, however, it is assumed that the baseline climate is at higher resolutions than resolutions of a global climate model. Consequently, high-resolution climate scenarios are obtained through a combination of high-resolution baseline data with coarse-scale information on climate change from global climate models. This straightforward approach has relatively low computational costs and has been used in many studies (Arnell, 2003; Diaz-Nieto and Wilby, 2005; Horton et al., 2010). This approach presents some limitations that project managers and decision makers should be aware of as they consider their downscaling approach(es). A summary of these limitations is provided below.

Limitations to Basic Downscaling Techniques

- Future climate scenarios only differ from the baseline climate in terms of the mean, maxima, and minima. All other statistics of the data remain the same.
- It is assumed that spatial climatic patterns remain unchanged in the future.
- The method needs to be adjusted for precipitation (e.g. Arnell and Reynard, 1996), because addition (or multiplication) of observed precipitation by GCM precipitation can alter the number of rain days and extreme-event size (Wilby et al., 2004). Also, if a study involves a time series of daily climate data, the temporal sequencing of wet and dry days remains unchanged.
- The method can be used to explore timeslices but not transient changes.

Source: Diaz-Nieto and Wilby, 2005

Despite substantial limitations to basic downscaling techniques, they are useful to project managers in some instances. Two examples include cases where the technique's limitations are not important in subsequent analyses that will use the data (see Figure 3) and cases where there are significant constraints to climate-scenario development (e.g. financial, workforce, and computing constraints) and other approaches are unviable.

UNINTELLIGENT METHOD

In addition to the change-factor method, project managers may consider using another similar basic approach referred to as the 'unintelligent' downscaling technique. This approach involves simple spatial interpolation between the center points of GCM grid cells to obtain estimates at the desired intermediate points that correspond to those in a higher-resolution baseline climate dataset (Wilby et al., 2004). The advantages and disadvantages of this approach are essentially the same as those for the change-factor method (see Table 8).

DEFINITION

Timeslices

A timeslice refers to a time period for which projections are given. The time period is usually centered around a given decade. For example, a 2050s time slice refers to the period from 2040–2069.

Table 8: Summary of pros and cons of the change-factor and unintelligent downscaling methods

Pros	Cons
● Straightforward	● Future climate scenarios only differ from the baseline climate in terms of the mean, maxima, and minima *(all other statistics of the data remain the same)* ● Spatial climatic patterns are assumed to remain unchanged in the future
● Low computational costs	● Method needs to be adjusted for precipitation (e.g. Arnell and Reynard, 1996), because addition (or multiplication) of observed precipitation by GCM precipitation can alter the number of rain days and extreme-event size (Wilby et al., 2004) ● The temporal sequencing of wet and dry days remains unchanged if a study involves time series of daily climate data
● Use in many studies	● Method can be used to explore timeslices but not transient changes

> “In addition to the change-factor method, project managers may consider using another similar basic approach referred to as the ‘unintelligent’ downscaling technique.”

Dynamical downscaling methods

Dynamical downscaling is another approach used to produce high-resolution climate scenarios, where Earth-system processes are mathematically represent in a way similar to GCMs but at a much higher resolution than typical global climate models. Unlike GCMs, the dynamical-downscaling approach is used to understand dynamics only for a portion of the Earth's surface. Dynamical downscaling is therefore substantially more complex than basic downscaling methods; it requires a considerable amount of observational data and sensitivity analyses (e.g. for selection of model parameters and settings) for proper use in a given location. Depending on constraints to climate-scenario development, it is not always a viable option.

The dynamical downscaling approach typically employs three main strategies:

- Limited-area modeling with regional climate models (RCMs)
- Stretched-grid modeling with GCMs
- Uniformly high resolution GCMs (also known as ‘time-slice climate simulation’) (Bader et al., 2008)

DEFINITION

Dynamical Downscaling

Dynamical downscaling refers to the use of techniques that mathematically represent Earth-system processes at high spatial resolutions (compared to typical GCMs) to produce high-resolution climate scenarios.

These dynamical approaches require a substantial amount of observational data and sensitivity analyses (e.g. for selection of model parameters and settings) for proper use in a given location.

A basic description of each of these dynamical approaches below is provided within this step. However, because the methods are complex, project managers and decision makers should first understand when a dynamical approach is a viable option for their region. There are several important factors that project managers should consider when assessing viability, including available scientific capacity and experience, sufficient financial resources, and quality of the available observational baseline.

Factors to Assess Viability of Dynamical Downscaling Approach

- **Scientific capacity and experience:** The proper use of dynamical downscaling for a region requires substantial scientific capacity and experience. As such, scientific experts familiar with climate modeling for the area of interest should be available to project managers and decision makers for this task. Ideally, this type of modeling should build upon previous efforts to model the region's climate. (An international effort that may soon provide this information for many regions is the Coordinated Regional climate Downscaling Experiment [CORDEX]. Information can be found at http://wcrp.ipsl.jussieu.fr/RCD_CORDEX.html.) In the absence of available scientific expertise and previous experience, dynamical downscaling approaches might be considered unviable due to the complexity of the method.
- **Resources:** Dynamical downscaling is generally the most computationally and data intensive method and requires substantial resources for analyses. Without adequate technical expertise, financial resources, and equipment, dynamical downscaling will be difficult to undertake.
- **Observational baseline:** As with all downscaling methods, good quality observations are needed to establish the baseline climatology. Without good to high quality baseline climatology, the utility of a downscaling with a complex dynamical method is questionable.

Equipped with an understanding of the limitations, project managers and their team of experts are prepared to review the main choices for dynamical downscaling approaches. A brief summary of the approaches follows. This should provide project managers with a basic understanding of each approach. Understanding the level of analyses associated with each approach will assist project managers with their selection of downscaling method. In practice, the method selection largely depends on the experience and skill of the scientific experts in a region.

LIMITED-AREA APPROACH

The limited-area approach involves choosing a model domain that covers only a portion of the Earth's surface (typically a continent or smaller) and using a regional climate model to simulate dynamics within the domain. This approach requires additional information on what is happening at boundaries of the selected domain. The additional information is typically either GCM output from the areas around the selected domain or observational data from atmospheric analyses (Bader et al., 2008). A strategy commonly associated with this approach is the use of multiple grids nested inside a coarser RCM simulation to achieve higher resolutions in the sub-regions of interest (e.g. Bader et al., 2008; Hay et al., 2006; Liang et al., 2001).

DEFINITION

Model Domain

A model domain is the region for which (climate-system) dynamics are simulated.

STRETCHED-GRID MODELING

Unlike the limited-area approach, this approach includes full global simulations with a GCM. A GCM is modified to have a grid with varying spatial resolution, where the highest resolutions are chosen for one or more regions of interest (Bader et al., 2008).

UNIFORMLY HIGH-RESOLUTION MODELING

Uniformly high-resolution modeling (time-slice climate simulation) also includes full global simulations with a GCM. It has a high-resolution grid extended to the entire globe, although analyses are still focused on particular regions of the Earth. This method is very computationally demanding. As such, it can only be used for relatively short simulation periods (hence its other name: time-slice climate simulation).

These dynamical methods are commonly used to produce climate scenarios at resolutions of several tens of kilometres, but resolution is sometimes increased to a few kilometres when using multiple nests (Bader et al., 2008). In some instances, dynamical downscaling may offer project managers clear advantages with regard to the accuracy of predictions. For example, the physically-based simulations at a higher resolution may improve the realism of climate scenarios. This was the case in a study discussed by Bader et al. (2008), which showed that RCMs can improve monsoon precipitation forecasts and interannual variability (although large-scale circulation patterns did not show a statistically significant improvement) (Mo et al., 2005). At the same time, Hay et al. (2006) demonstrated that high-resolution simulation does not always guarantee better results (specifically for precipitation timing and intensity). It is important to emphasize, therefore, that **physically based, high-resolution simulations do not guarantee the best results**. Whether high-resolution simulation improves predictions in a given region will depend on, among other things, the characteristics of the region and is an active area of scientific research. Project managers with substantial resources should be careful not to assume that the most complex method will yield the most reliable climate scenarios.

> “Whether high-resolution simulation improves predictions in a given region will depend on, among other things, the characteristics of the region and is an active area of scientific research.”

A summary of the three main downscaling techniques follows (Table 9), as well as a suggested worksheet to assess the viability of downscaling approaches (Table 10).

Table 9: **Summary of dynamical downscaling techniques**

Dynamical Downscaling	
There are three main dynamical downscaling techniques: 1) limited-area modeling with RCMs; (2) stretched-grid modeling with GCMs; and (3) uniformly high resolution GCMs (also known as 'time-slice' climate simulation).	
Pros	**Cons**
● Climate information is derived from physically based models ● Climate variables are available at high spatial and temporal resolutions ● Many climate variables are available	● Computationally expensive ● Parameterization issues are challenging and scale dependent ● Results are sensitive to domain specification
Example	
The Second National Communication for Argentina included dynamical downscaled climate scenarios with the well-known PSU/NCAR mesoscale model. Additional details are in the Annex.	
Comment	
Dynamical downscaling is more complex than the basic downscaling methods. It is able to provide physically based, high-resolution simulations, but these do not always guarantee the best results. Whether high-resolution simulation improves predictions in a given region will depend on, among other things, the characteristics of the region and is an active area of scientific research.	

Note: See Table 1 of Mearns et al. (2003) for more details.

Table 10: **Suggested worksheet to assess viability of downscaling approaches**

Limitation	Availability	Comment
Scientific capacity and experience		
Resources		
Observational baseline		

Statistical downscaling methods

As the previous discussion demonstrates, the complexity of downscaling techniques spans a wide range, from the simple change-factor method to the complex dynamical downscaling methods with regional climate models. Project managers and decision makers might look for an intermediate approach that strikes a balance between simplicity and complexity. Statistical downscaling strives to reach such a balance, especially in terms of computational resources.

DEFINITION

Statistical Downscaling

Statistical downscaling is another downscaling approach to produce high-resolution climate-scenarios. This technique involves development of statistical relationships between large-scale atmospheric variables (e.g. GCM output) and local variables (e.g. meteorological station observations).

Statistical downscaling involves development of statistical relationships between large-scale atmospheric variables (e.g. GCM output) and local variables (e.g. meteorological station observations). This method is therefore based on the influence of the large-scale climatic state and the regional physiographic features (e.g. topography, land use) on a region's climate (Wilby et al., 2004). A wide variety of statistical downscaling methods have been developed in scientific literature. These methods vary in terms of complexity and focus. For a project manager, it is useful to at least be aware of the three broad categories for statistical downscaling. These three categories, as classified by Wilby et al. (2004), are (1) regression models, (2) weather classification, and (3) weather generators. Although the methodologies of these techniques vary significantly, it is helpful for project managers to understand the two main steps common to all of these approaches.

Main Steps Common to All Statistical Downscaling Approaches

- A statistical model is developed in order to relate large-scale variables (predictors) to local variables (predictands).
- The large-scale GCM output is then fed into the derived statistical model in order to produce an estimate of the local variables.

Project managers will find the statistical approach attractive because it is computationally inexpensive relative to approaches using dynamical downscaling. Also, the approach can then be applied to output from multiple GCMs to provide a distribution of future climate predictions. Despite the advantages of statistical downscaling, project managers and their teams also need to understand the approach's limitations (see Box 5). The key theoretical weakness of the approach is that it is not known whether the statistical relationships derived for the present climate will remain the same for future climate conditions, which is the main assumption of the approach (Wilby et al., 2004).

> “Project managers with substantial resources should be careful not to assume that the most complex method will yield the most reliable climate scenarios.”

As a method of intermediate complexity, statistical downscaling is more computationally demanding than basic methods but less so than the dynamical methods. It terms of skill, statistical and dynamical downscaling are of comparable skill in producing accurate climate scenarios, while the basic approaches are generally the least skillful. It should be emphasized, however, that project managers should not select a downscaling method based on a single criterion (e.g. skill of the method). Table 11 provides a brief summary of the statistical downscaling techniques.

Box 5: Real-World Application of Statistical Downscaling to Illustrate Potential Limitations of the Approach

As a real-world example, we can consider monsoon dynamics in India. If we were using statistical downscaling for India, we might derive a statistical relationship between GCM rainfall and rainfall observed at meteorological stations. For future climate predictions, we would then use this statistical relationship, which was derived based on the present-day climate. Yet future monsoons may be quite different from present-day monsoons, especially in terms of monsoon frequency and intensity. In that case, the future predictions derived from the present-day statistical relationship would need to be reevaluated.

Table 11: Statistical downscaling techniques

Pros	Cons
● Cost of computation is inexpensive relative to dynamical downscaling approaches ● Generates information at high resolution or on non-uniform grids ● Applicable to output from multiple GCMs to provide a range of future climate predictions	● Unknown whether the statistical relationships derived for the present climate will remain the same for future climate (Wilby et al., 2004) ● Often requires daily observations
Example	
Statistical downscaling was used to produce future precipitation scenarios for southern Africa in order to inform decisions related to agricultural investment. Additional details are in the Annex.	
Comment	
Statistical downscaling is computationally inexpensive relative to approaches using dynamical downscaling. Also, the approach can then be applied to output from multiple GCMs to provide a distribution of future climate predictions. Despite the advantages of statistical downscaling, project managers and their teams also need to understand the approach's limitations.	

Note: See Table 1 of Mearns et al. (2003) and Table 1 of Wilby et al. (2004) for more details.

4.3 Document Climate-Scenario-Development Process

Documenting the climate-scenario development process is an important step for project managers and their teams of experts to follow. It provides a written history of the process that can be shared with other colleagues as a learning tool and real-world case study. In developing countries, where resources of all kinds are finite, this type of recording is particularly helpful. Project managers may find it useful to create a report structure based on the proposed framework and to make use of the worksheets and tables presented in this guidebook to collect and summarize key information. Other teams will benefit from information ranging from the make up of the scenario-development team to an assessment of the pros and cons of a downscaling technique in a specific case, as well as a list of important references consulted. Documenting the process also provides managers with detailed information for end users and donors.

> “The choice of model method and approach is based on the accumulation of facts obtained and analyses undertaken throughout the climate-scenario development process. The quality of the scenario inputs influences integrity and usefulness of the scenario output and drives the type of model and approach selected for a given assessment.”

Summary

The choice of model method and approach is based on the accumulation of facts obtained and analyses undertaken throughout the climate-scenario development process. The quality of the scenario inputs influences integrity and usefulness of the scenario output and drives the type of model and approach selected for a given assessment. There are basic approaches, such as spatial analogue and arbitrary, which do not require expensive and highly technical computational methods to derive predictions. These methods may be less accurate, but not necessarily, than the more sophisticated downscaling techniques reviewed in this chapter, which may provide climate information at a level of resolution that is high enough to inform decisions at the regional and local level. If forecasting is accurate enough at this level, policies can be put in place to assist areas with low-emission climate-resilient development strategies that promote important development goals and safeguard against the potential negative (and capitalize on any positive) impacts associated with climate change.

Documenting how teams were put together and decisions were made throughout the climate-scenario development process is important as it serves as a roadmap for future projects. It also can assist team members along the way in retracking their steps and understanding their choices. In addition, the documentation informs ends users on what went into making the end product, including all relevant assumptions and uncertainty parameters.

In summary, climate scenarios are uncertain by nature but can serve as a useful planning tool. The UNDP framework presented in this guidebook provides a structure for climate-scenario development that seeks to build relevant ranges of scenarios that strengthen policies and support low-emission climate-resilient futures.

Chapter 5

Conclusion

Conclusion

“Project managers and decision makers in developing countries will benefit from the framework’s structure and content, because it provides step-by-step guidance and organization to an otherwise daunting task.”

This guidebook presented a framework for the development of climate-scenarios to support low-emission climate-resilient development strategies. It provided a step-by-step process to guide project managers and their team of experts through the entire climate-scenario-development process: from the identification of needs to the selection of models and downscaling techniques. Because climate-scenario development is highly technical in nature and complicated under any set of circumstances, this guidebook is especially valuable to developing countries where technical and financial resources are not necessarily abundant. Following the prescribed framework will streamline the scenario development process and assist developing countries as they look to the future where they are able to simultaneously adapt to climate change and pursue sustainable development.

The overview to this report set the context for why a climate-scenario-development framework would be useful to developing countries. Project managers and decision makers in developing countries will benefit from the framework's structure and content, because it provides step-by-step guidance and organization to an otherwise daunting task.

The first chapter of this guidebook presented the first step in the climate-scenario development process: (1) building a crosscutting team; (2) determining climate-scenario-development needs; and (3) evaluating climate-scenario development needs. Building a strong team of experts is essential to any project. Given the complexity of climate-scenario development, it is especially important to this process. Project managers are generally well equipped to manage the climate-scenario-development process. By design, their job requires them to manage people, funds, project objectives, and schedules. In many cases, however, the project manager may not be fully versed in climate-change modeling. For this reason, s/he will need to identify and bring together technical experts and end users to assist along the way. The technical experts provide input and advise on the scientific issues and the end users provide insight on how the scenarios will be used. Both of these inputs are critical to the project manager as s/he balances the needs versus the constraints.

Chapter 2 of the report focused in on identifying the specific regional constraints that will impact what model and approach project managers choose for climate-scenario development. The step in this chapter built on the questions and work the team undertook in Chapter 1. It is here where the project manager identifies the scientific and non-scientific constraints and balances them against the needs identified by the technical experts and scenario end users. The completion of this step should result in the production of a realistic climate-scenario-development plan. In other words, a plan that sets the scenario ambition and level of complexity in line with the existing constraints.

Once the project manager and his/her team of experts have completed Steps 1 and 2, they are able to move on to the next step addressed in Chapter 3: Uncertainty and climate-scenario development. This chapter identified the main uncertainties associated with climate-scenario development and provided two examples to show how to manage the uncertainties and select the appropriate and most effective climate-scenario model and, when relevant, downscaling technique. The figures in this chapter illustrated the relationships quite well.

With a firm grasp on what the needs and constraints are for a given climate scenario and a strong understanding of the uncertainties that will be encountered during climate-scenario development, project managers and their teams are ready to select an appropriate climate model and downscaling technique in cases where such an application was deemed appropriate. Chapter 4 outlined the general procedures for climate-scenario development and provides an overview of the main methods for climate-scenario development. More basic approaches are summarized as alternatives to the more technical downscaling techniques. After reading this chapter, project managers and their teams should have a complete picture of what their climate-scenario-development process will entail, including their choice of model approach.

> “With a firm grasp on what the needs and constraints are for a given climate scenario and a strong understanding of the uncertainties that will be encountered during climate-scenario development, project managers and their teams are ready to select an appropriate climate model and downscaling technique in cases where such an application was deemed appropriate.”

The last remaining task is to document the results from each step. It is important for institutional purposes to record how teams came to the decisions they made. It also informs the end users and any donors that seek detailed reporting. Although this point comes last, it is one of the most important steps in the climate-scenario development process. There are tables and worksheets presented in throughout the report that can be used as examples to document thought and decision-making processes.

The annex to this report offers downscaling case studies from developing countries. These provide an example of real-world experiences and highlight the complexity of the task at hand as well as the importance of following a solid framework for climate-scenario development.

The references to the report provide the reader with additional resources as well as give credit to studies and authors that were consulted during the drafting of this report.

Annex
Downscaling Case Studies

- **Case Study 1** — Downscaling of Future GCM-Based Climate Scenarios: Argentina's Second National Communication to the UNFCCC
- **Case Study 2** — Downscaling in Uruguay: Combining a Regional Climate Model Approach with Statistical Downscaling to Support LECRDS
- **Case Study 3** — Downscaling Rainfall for Southern Africa: Assessing Rainfall Scenarios through Regional Climate-Scenario Development

Downscaling Case Studies

While the discussions of basic downscaling principles in this guidebook are highly valuable in the process of scenario development, individual consideration is needed for each region. Factors that differentiate regions in terms of downscaling analyses include physical and climatic characteristics, region size, data availability, and intended use of downscaled climate scenarios. These factors may even preclude the use of certain downscaling approaches for certain cases.

It is important for project managers to understand how these factors influence climate-scenario development. Evaluation of different case studies can be an important means to achieving this understanding. Three downscaling case studies are presented in this section to illustrate how these factors were addressed in real-world situations. Each study is different in terms of regional characteristic and intended use of climate scenarios.

Case Study 1: Climate-scenario development in Argentina — The first case study presents Argentina's climate-scenario development as documented in its Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC). Argentina's SNC is one of the 102 National Communications from Non-Annex I parties that UNDP has actively supported since 1996. The focus of the climate-related portion of the assessment is to initiate a broad discussion on climate change for the regions of Argentina.

Case Study 2: Climate-scenario development in Uruguay — The second case study presents climate-scenario development at a much smaller spatial scale for a Uruguayan territory. This UNDP-supported downscaling effort is intended to inform investment plans on climate change for multiple sectors as part of the region's low-emission climate-resilient development strategy.

Case Study 3: Climate-scenario development in southern Africa —The final case study is a regional analysis for a portion of southern Africa. This climate-scenario development is limited to precipitation downscaling for agricultural investment — a limitation influenced by end-user needs.

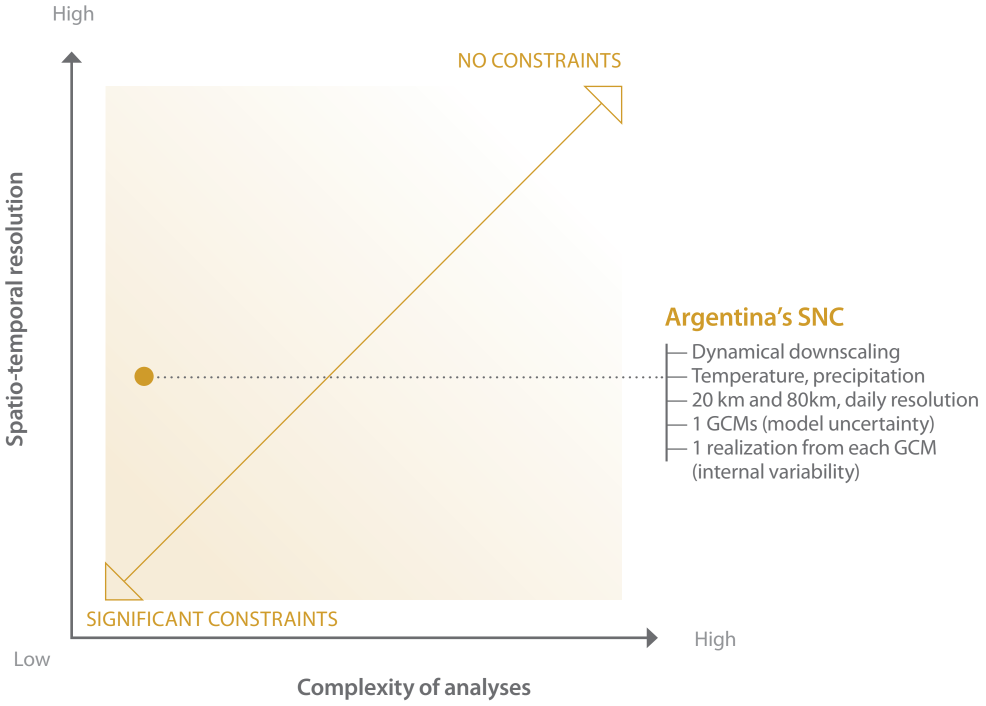
The following case studies demonstrate the diversity of issues involved in climate-scenario development. They should also provide perspective to project managers on the relationship between a study's ambitions (meaning what it intends to achieve) and its level of climate-scenario development. This perspective should assist them in their efforts to identify appropriate levels of climate-scenario development based on their project's goals.

Case Study 1

Downscaling of Future GCM-Based Climate Scenarios: Argentina's Second National Communication to the UNFCCC

As part of Argentina's SNC, a UNDP-supported assessment was published (Argentina, 2007) that included a climate-change-vulnerability analysis at the national scale. Both present-day climatology (along with recent observed trends) and future climate scenarios were evaluated for the entire country, which covers an area over 2,700,000 km^2. The aim of this analysis was to initiate a broad dialogue on climate-change vulnerability and planning for the different regions of the country. In this capacity, the SNC provided an essential first step to promoting an understanding of future climate scenarios in Argentina.

Figure A-1: Characterization of climate-scenario development in the Argentine SNC in terms of analysis complexity, spatial-temporal resolution, and non-scientific constraints to climate-scenario development



The general procedure for climate-scenario development was followed in Argentina (see Chapter 4). To begin with, and to establish the required observational baseline-climate, data was collected and analysed on the 20th century precipitation trends, extreme precipitation, and temperature. The report identified the importance of the El Niño-Southern Oscillation (ENSO) to interannual climate variability for the country, and that the average annual rainfall increased over most of the Argentine territory, except for the Andes. The SNC also noted a trend towards more frequent extreme rainfall events (defined as larger that 100 mm per event, where the event is not longer than 2 days). These findings successfully provided the climate-scenario-development team with a broad overview of the current Argentine climatology.

The observed changes in 20th century climate (i.e. precipitation and temperature) that resulted from analysis above were used to understand regional water resources in Argentina, including flow changes of major river networks as well as general implications for the extent of rainfed agriculture. Therefore, the ambition of the climate-scenario development was to understand regional water resources in Argentina. With the ambition clearly defined, the next step was to select the appropriate climate-scenario method (Step 2 of climate-scenario development general procedures).

It was determined that downscaling of future GCM-based climate scenarios was needed, because the low resolution of GCMs was considered insufficient to predict precipitation accurately, particularly in the Andes Mountains. Consequently, Argentina's Research Center of the Sea and the Atmosphere (CIMA) conducted dynamical downscaling analyses for the country.

> **Model:** A single GCM (the HadCM3 global model — developed by the Hadley Centre in the UK) was chosen to apply dynamical downscaling. This model was selected, because previous analyses showed it to be relatively skillful at representing the southern South American climate (temperature, sea level pressure, and precipitation).
>
> **Downscaling Approach:** The dynamical downscaling was accomplished using the well-known PSU/NCAR mesoscale model (known as MM5) at multiple spatial resolutions. Although unclear from the SNC, downscaling was done at two spatial resolutions by CIMA, 20 km and 80 km for southern South America. Projected changes were discussed for two periods (2020–2030 and 2080–2090), and two emissions scenarios (the IPCC SRES A2 and B1 scenarios) were used for this analysis. The results from these downscaling provided future scenarios of the mean temperature and precipitation (Step 3 of the climate-scenario development general procedures).

Results

The climate-scenarios resulting from the processes above, and presented in the SNC, provided useful input to inform decision makers on important climate-related vulnerabilities for Argentina. A summary of some of the main findings of the SNC climate analysis is summarized below.

- There will be an increase in average temperature for all Argentine territories
- Several regions of Argentina (Cordillera of the Andes, northwestern Patagonia, and Comahue) will experience a reduction in average rainfall, while the rest of the country will experience no change in average rainfall
- The frequency of extreme precipitation will continue to increase in the future

Analysis of the Argentine case study

Figure A-1 illustrates how project managers might assess analysis complexity, spatial-temporal resolution, and non-scientific constraints for this Argentine case study. First, the region's size (i.e. all of Argentina) is relatively large and its physical geography has significant heterogeneity. With regard to the complexity of the analyses, a dynamical downscaling technique was selected. However, because dynamical downscaling is computationally intensive, investigators limited their analyses to only one GCM (likely due to financial and time constraints). Therefore, model uncertainty was not evaluated as part of the downscaling process. Recognizing this limitation, the report does present temperature and precipitation scenarios (not downscaled) from multiple GCMs based on the IPCC AR4 simulations. As for internal variability uncertainty, it is not clear whether multiple realizations of the HadCM3 global model were used, but no analyses discussing internal climate variability were presented. Emissions uncertainty was accounted for by considering two emissions scenarios, which is consistent with our proposed framework in Figure 1.

Overall, the complexity of the analyses might be considered to be relatively low based on all components of the climate-scenario development. The spatio-temporal resolution might be considered to be at a relatively moderate level. These designations are subjective and only provided here for illustrative purposes to assist project managers and scientific experts in using this tool for their own analyses.

In the Argentine SNC, climate scenarios are discussed within the context of multiple issues including: water stress in the northern and central regions of Argentina, heat waves, changes to flow of the River Plate Basin (Río de la Plata), extreme rainfall and flooding, agriculture, health (including the geographical distribution of vector-borne tropical diseases disease), energy, and tourism. Each of these issues will have different requirements of the climate scenarios in terms of their accuracy and resolution. For example, Argentine agricultural analyses will be very sensitive to accurate predictions of daily and extreme (i.e. heat and cold waves, droughts and flooding) temperature and precipitation.

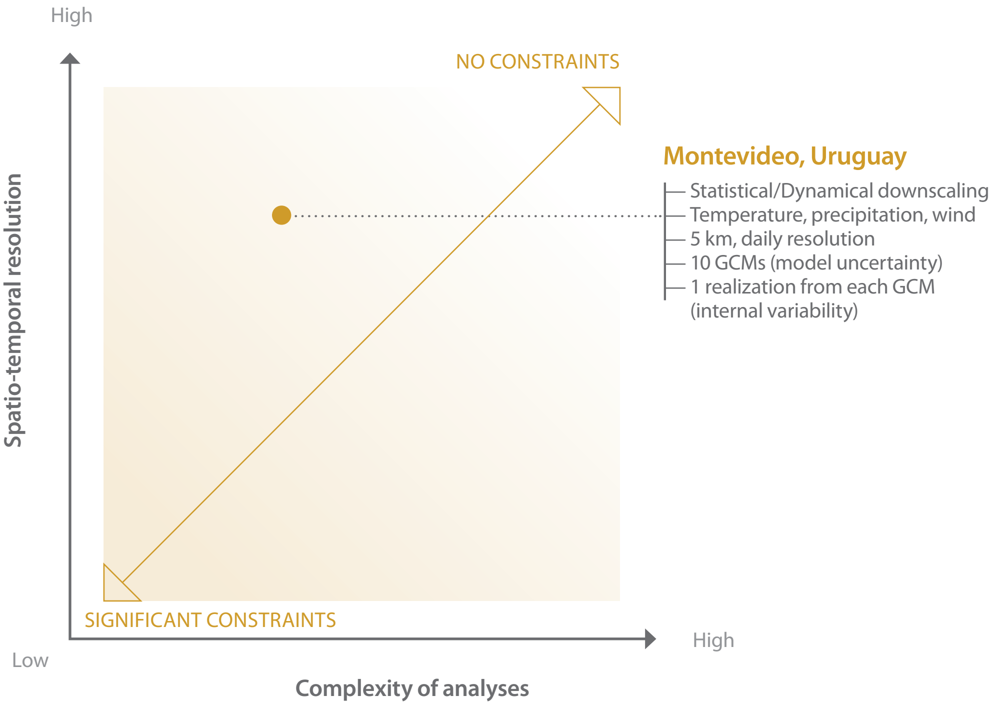
These conclusions are instructive, in that they provide a basis for dialogue on climate change vulnerability, adaptation, and mitigation. Future efforts on climate-scenario development for Argentina can benefit from the discussions of this guidebook. As efforts move towards the use of climate scenarios for investment decisions, robust **prospective ranges of climate scenarios** will be critical.

Case Study 2

Downscaling in Uruguay: Combining a Regional Climate Model Approach with Statistical Downscaling to Support LECRDS

The metropolitan region (9,900 km^2) of Montevideo, Uruguay and the surrounding departments of San José and Canelones were the focus of a recent UNDP-supported pilot project to prepare future climate scenarios as part of LECRDS. The downscaling analyses for Montevideo/San José/Canelones were performed by ClimSAT, a scientific center supporting developing countries in the preparation of their LECRDS, in collaboration with MétéoStrategy, Climpact and Ifremer. The objective was to provide current and future climatological data at high spatial and temporal resolution that could be used for local vulnerability and adaptation planning by multiple sectors. Efforts were also made to conduct uncertainty analyses as a step towards the development of a prospective range of climate scenarios.

Figure A-2: Characterization of climate-scenario development for the Montevideo region's LECRDS in terms of analysis complexity, spatial-temporal resolution, and non-scientific constraints to climate-scenario development



The downscaling approach involved the combination of a regional climate model (downscaling) and statistical downscaling.

> **Method:** A regional climate model (dynamical downscaling) was used to produce a high-resolution (5-km) climatology for the region.
>
> **Downscaling approach:** A statistical downscaling approach (Michelangeli et al., 2009) was used to produce climate scenarios for two future time-slice periods and two SRES emissions scenarios. These climate projections were produced using a statistical approach, because dynamical downscaling at 5-km resolution would have been too costly and time intensive.

Analysis of the Uruguayan case study

Figure A-2 illustrates how project managers might characterize the analysis complexity, spatial-temporal resolution, and non-scientific constraints for the Montevideo study. The region's size is relatively small. As for its physical geography, the topography is generally flat but winds are highly variable depending on distance from the coast. A high resolution (5 km) was selected for the analyses to deal with this variability. In fact, this case is an interesting example because two downscaling approaches are combined: dynamical downscaling for a present-day climatology and statistical downscaling for future scenario development.

Overall, the complexity of the analyses might be considered as moderate based on all components of the climate-scenario development (described further below). As with the previous case study, this designation is for illustrative purposes to assist project managers and scientific experts in using this tool.

To provide the context of these analyses to project managers and scientific experts, we summarize the climate-scenario development for Montevideo. ClimSAT's climate datasets are described below:

Present-day climatology: Station observations are limited in the region, such that a dynamical downscaling approach was used to downscale the NCEP/NCAR/DOE Reanalysis (a global, model reconstruction of weather variables (Kalnay et al., 1996; Kanamitsu et al., 2002). The Weather Research and Forecasting Model (WRF) (Skamarock et al., 2008) was used to downscale from a resolution of about 250 km × 250 km to 5 km × 5 km for 1970 to 1999. The WRF output then contains 30 climatic variables (temperature, precipitation, wind speed, etc.) at spatial and temporal resolutions of 5 km × 5 km and 3 hours, respectively. It is important to note that, although project managers may consider the use of models such as WRF to generate a present-day climatology, it is critical that the current climatology is based on available observations. In the absence of high-resolution observations, project managers should consider lower resolution and less complex analyses.

Future climatology: Two timeslices were selected, 2046 to 2065 and 2081 to 2100. Over these periods, a statistical approach was used to produce daily data at 5 km × 5 km through downscaling of temperature and precipitation output from 12 IPPC models for two SRES scenarios (B1 and A2).

A high spatial resolution (5 km) was chosen that required the use dynamical downscaling to produce a high-resolution present-day climatology. Project managers should be cautious of model-based approaches for deriving present-day climatologies (rather than through use of observations). That is, an issue with the dynamical downscaling (with WRF or similar-type models) is that substantial effort must be made to parameterize and evaluate that model for a given region and scale of analysis. For example, the WRF model has many different options available with which to represent atmospheric processes. Care must be taken because the choice of what to represent and how to represent it will vary depending on the characteristics of the region and what resolution is required of the output (e.g. 5 km versus 20 km). These decisions may lead to significant differences in predictions of present-day climatology.

ClimSAT chose the 5-km resolution, because Montevideo/San José/Canelones is a coastal region for which climate gradients might be important. Subsequent analyses on prediction of present-day climatology were done to evaluate the value of downscaling to 5 km relative to a coarser resolution. Making use of (intermediate) 25-km downscaling results, they found that downscaled predictions from the 5-km and 25-km simulations were statistically very similar, whereas statistically significant differences were present between the very coarse NCEP/NCAR/DOE Reanalysis data and the downscaled results. Additionally, a comparison with station data revealed that both the 5-km and 25-km predictions were more consistent than the NCEP/NCAR/DOE Reanalysis data were compared to station observations. This result demonstrates that climate-scenario results are improved by downscaling and also that higher resolution does not imply more accurate climate scenarios. That is, downscaling to 5 km is not superior to 25-km downscaling in this case.

Importantly, uncertainty analyses were conducted as part of the Montevideo climate-scenario development. With regard to the main uncertainty types, model uncertainty was accounted for using 12 IPCC models, while emissions uncertainty was considered through use of two SRES scenarios. As with the Argentine SNC, internal variability uncertainty was not extensively explored. Also, only one downscaling technique was used for future scenarios. Ideally, although not done here due to time/financial constraints, it is beneficial to consider multiple downscaling approaches to fully explore downscaling uncertainty, given that different methods often lead to different predictions (e.g. Wilby, 2008).

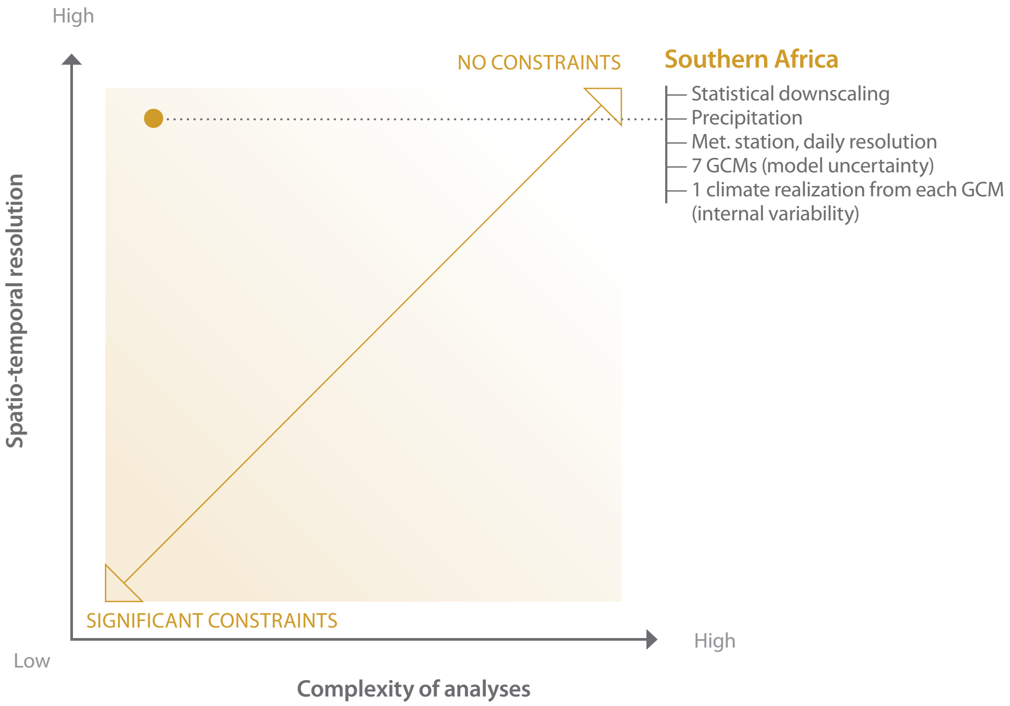
One important preliminary finding from uncertainty analyses by ClimSAT (Lemarié and Honnorat, in preparation; Loukos et al., in preparation) is that precipitation predictions have higher uncertainty relative to temperature predictions; results that are in line with other findings in the scientific literature. This uncertainty demonstrates the need to provide a **prospective range of climate predictions**, even if the range is large. In the next case study, we focus on precipitation downscaling given its importance in LECRDS.

Case Study 3

Downscaling Rainfall for Southern Africa: Assessing Future Rainfall Scenarios through Regional Climate-Scenario Development

As the Uruguayan downscaling analyses demonstrated, regional climate-scenario development for rainfall (precipitation) is particularly challenging. This is a problem and a significant issue considering that rainfall prediction is key to most vulnerability, adaptation, and mitigation assessments. To provide guidance on this issue, the following case study focuses on precipitation-scenario development for a portion of southern Africa. The challenge of precipitation downscaling is particularly daunting in this case study because of the low density of observations and the high dependence on rural agriculture (Tadross et al., 2009) in the area. This case should serve as an excellent example for developing countries involved in LECRDS production because they are likely to face similar issues.

Figure A-3: Characterization of climate-scenario development for southern Africa in terms of analysis complexity, spatial-temporal resolution, and non-scientific constraints to climate-scenario development



This regional analysis focused on a portion of southern Africa that covers an area of about 2 million km^2 (somewhat smaller than Argentina) and includes Malawi, Mozambique, Zambia and Zimbabwe. The analyses were conducted by Tadross et al. (2009) to assess future rainfall scenarios for the region and how the future changes in rainfall might impact maize cultivation. Importantly, the intended application for the future rainfall scenarios controls the downscaling approach to a significant extent. That is, potential rainfall changes are important as they relate to the crop phenological cycle. Therefore, daily downscaling of rainfall — rather than monthly — is needed, because rainfall shifts of a several days to a couple of weeks can have dramatic effects on crop production and agricultural management decisions.

Figure A-3 illustrates how project managers might characterize the analysis complexity, spatial-temporal resolution, and non-scientific constraints for this southern Africa study. The heterogeneity of this southern Africa region is relatively moderate, while the region's size is moderate to large (especially in comparison to Montevideo).

> **Downscaling approach:** A statistical downscaling approach was used to predict future rainfall scenarios in this southern Africa region (see Hewitson and Crane [2006] for details on the approach).
>
> **Method:** The method was applied to present-day and future (2046–2065) periods for precipitation predictions from 7 GCMs and one emissions scenario. The predictions therefore account for model uncertainty but not emissions, climate-variability, and downscaling uncertainties.

DEFINITION

Boxplot

A boxplot is a useful way to graphically depict groups of data through their five-number summaries: the sample minimum (smallest observation), lower quartile (Q1), median (Q2), upper quartile (Q3), and sample maximum (largest observation).

Overall, the complexity of the analyses could be considered as low because the downscaling is only done for precipitation, and it only considers a single emissions scenario. (For precipitation alone, the analysis complexity could be considered relatively high.) As with the previous case studies, this designation is for illustrative purposes only. The relative resolution of this analysis (i.e. a daily timescale with a spatial scale corresponding to that of a meteorological station) is also qualitatively approximated to be high.

To place this study in context for project managers and scientific experts, some main details are provided below. The prospective range of rainfall scenarios (with the previously described limitations) in this study were presented in a useful way. Boxplots of total monthly rainfall, monthly number of rain days, maximum dry spell length, and median daily rainfall intensity were used (Figures 11 and 12 in Tadross et al. [2009]) to communicate the prospective rainfall. This type of detailed information is critical for investment-related projects, where the variables needed are determined by the target application.

This study also shows that it is often beneficial to coordinate downscaling efforts with vulnerability studies. In this assessment, present-day analyses were accompanied by analysis of the link between observed changes in daily rainfall and agriculture (including crop growth and farm management decisions). This link was analysed through the development of indices — based on rainfall frequency and intensity — that represent agricultural variables, including planting dates, dry spell length, frequency of dry days, rainfall intensity and total rainfall during critical stages of the crop growth cycle. Further, these variables were analysed in terms of their connections to large-scale climate dynamics (El Niño-Southern Oscillation and Antarctic Oscillation) by analysing observed daily rainfall data. These agricultural analyses involved analyses of present-day climate data. Therefore, if a project manager can determine — prior to the climate scenario development — that certain sectoral assessments will be needed, the manager should communicate this need to the scientific experts to possibly coordinate concurrent analyses.

References

Argentina. 2007. *Comunicación Nacional de la República Argentina a la Convención Marco de las Naciones Unidas sobre Cambio Climático.* Republic of Argentina. Available online at: http://www.ambiente.gov.ar/archivos/web/UCC/File/Segunda%20Comunicacion%20Nacional.pdf

Arnell, N., and N. Reynard. 1996. "The Effects of Climate Change Due to Global Warming on River Flows in Great Britain." *Journal of Hydrology 183* (3-4): 397-424. Available online at: http://www.sciencedirect.com/science

Arnell, N. 2003. "Relative Effects of Multi-Decadal Climatic Variability and Changes in the Mean and Variability of Climate Due to Global Warming: Future Streamflows in Britain." *Journal of Hydrology 270* (3-4): 195-213. Available online at: http://www.sciencedirect.com/science

Bader, D., et al. 2008. *Climate Models: An Assessment of Strengths and Limitations*, report by the U.S. Climate Change Science Program and the Subcommittee on Global Change, Research Department of Energy, Office of Biological and Environmental Research, Washington, D.C., 123. Available online at: http://www.clivar.org/organization/wgcm/references/sap3-climate-models.pdf

Carter, T. 2007. *General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment, Version 2, Task Group on Data and Scenario Support for Impact and Climate Assessment* (TGICA). Intergovernmental Panel on Climate Change (IPCC), Geneva. Available online at: http://www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf

Christensen, J., et al. 2007. *Regional Climate Projections, Climate Change, 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC*, University Press, Cambridge, UK. Available online at: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

Diaz-Nieto, J., and R. Wilby. 2005. "A Comparison of Statistical Downscaling and Climate Change Factor Methods: Impacts on Low Flows in the River Thames, United Kingdom." *Climatic Change 69* (2): 245-268. Available online at: http://www.mendeley.com/research/a-comparison-of-statistical-downscaling-and-climate-change-factor-methods-impacts-on-low-flows-in-the-river-thames-united-kingdom/

Hawkins, E., and R. Sutton. 2009. "The Potential to Narrow Uncertainty in Regional Climate Predictions." B*ulletin of the American Meteorological Society 90* (8): 1095-1107. Available online at: http://centaur.reading.ac.uk/1766/

Hay, L., et al. 2006. "One-Way Coupling Of an Atmospheric and a Hydrologic Model in Colorado." *Journal of Hydrometeorology 7* (4): 569-589. Available online at: http://journals.ametsoc.org/doi/pdf/10.1175/JHM512.1

Hewitson, B., and R.G. Crane. 2006. "Consensus Between GCM Climate Change Projections with Empirical Downscaling: Precipitation Downscaling over South Africa." *International Journal of Climatology 26* (10): 1315-1337. Available online at: http://geog.ucsb.edu/~joel/g280_s09/student_contrib/glenday/hewitson.pdf

Horton, R., et al. 2010. "New York City Panel on Climate Change 2010 Report, Chapter 3: Climate Observations and Projections." *New York Academy of Sciences* 1196: 41–62. Available online at: http://onlinelibrary.wiley.com/doi/10.1111/j.1749-6632.2009.05314.x/full

Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the IPCC*, Cambridge, U K and New York, USA: Cambridge University Press, 881. Available online at: http://www.csun.edu/~hmc60533/CSUN_630E_S2004/climate%20change/climate_change_2001_tech_summary.pdf

Kalnay, E., et al. 1996. "The NCEP/NCAR 40-year Reanalysis Project." *Bulletin of the American Meteorological Society 77* (3): 437-471. Available online at: http://journals.ametsoc.org/doi/pdf/10.1175/1520-0477%281996%29077%3C0437%3ATNYRP%3E2.0.CO%3B2

Kanamitsu, M., et al. 2002. "NCEP-DOE AMIP-II Reanalysis (R-2)." *Bulletin of the American Meteorological Society 83* (11): 1631-1643. Available online at: http://www.mendeley.com/research/ncepdoe-amipii-reanalysis-r2/

Khalil, A., et al. 2010. "Predictive Downscaling Based on Non-Homogeneous Hidden Markov Models." *Hydrological Sciences Journal 55* (3): 333-350. Available online at: http://www.informaworld.com/smpp/content~db=all~content=a921561994~frm=titlelink?words=khalil&hash=2771316581

Knutti, R., et al. 2010. *Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections*. Prepared for the Meeting Report of the IPCC Expert Meeting on Assessing and Combining Multi Model Climate Projections IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland. Available online at: http://www.ipcc.ch/pdf/supporting-material/expert-meeting-assessing-multi-model-projections-2010-01.pdf

Lemarié, F., and M. Honnorat. "The Coupled Multi-Scale Downscaling Climate System: a Decision-Making Tool for Developing Countries." Available online at: http://www.climsat.org/

Liang, X., et al. 2001. "Development of a Regional Climate Model for US Midwest Applications. Part I: Sensitivity to Buffer Zone Treatment." *Journal of Climate 14*: 4363-4378. Available online at: http://journals.ametsoc.org/toc/clim/14/23

Loukos, H., et al. "Uncertainty Evaluation in the UNDP/ClimSAT Territorial Climate Profiles." Available online at: http://www.climsat.org/

Lu, X. 2006. *Guidance on the Development of Regional Climate Scenarios for Application in Climate Change Vulnerability and Adaptation assessments* within the Framework of National Communications from parties not included in Annex I to the United Nations Framework Convention on Climate Change. New York: National Communications Support Programme, UNDP-UNEP-GEF, 42. Available online at: http://ncsp.undp.org/sites/default/files/NCSP_climate_scenarios_guidance_0.pdf

Lu, X. 2007. *Applying Climate Information for Adaptation Decision-Making: A Guidance Resource Document*. New York: National Communications Support Programme, UNDP-UNEP-GEF. Available online at: http://unfccc.int/files/adaptation/sbsta_agenda_item_adaptation/application/pdf/ncsp_guidance_adaptationdecisionmaking.pdf

McGuffie, K., and A. Henderson-Sellers. 2005. *A Climate Modelling Primer*. Wiley. Available online at: http://www.amazon.com/Climate-Modelling-Primer-Kendal-McGuffie/dp/047085751X

McMichael, A.J., et al., eds. 2003. *Climate Change and Human Health: Risks and Responses*, World Health Organization, Geneva. Available online at: http://www.who.int/globalchange/publications/climchange.pdf

Mearns, L., et al. 2003. *Guidelines for Use of Climate Scenarios Developed from Regional Climate Model Experiments*, Published by the Data Distribution Centre of the Intergovernmental Panel on Climate Change. Available online at: http://www.ipcc-data.org/guidelines/dgm_no1_v1_10-2003.pdf

Michelangeli, P., et al. 2009. "Probabilistic Downscaling Approaches: Application to Wind Cumulative Distribution Functions." *Geophysical Research Letters 36* (11): L11708. Available online at: http://www.agu.org/pubs/crossref/2009/2009GL038401.shtml

Mo, K., et al. 2005. "Impact of Model Resolution on the Prediction of Summer Precipitation over the United States and Mexico." *Journal of Climate 18*: 3910-3927. Available online at: http://journals.ametsoc.org/doi/abs/10.1175/JCLI3513.1

Moss, R., et al. 2010. "The Next Generation of Scenarios for Climate Change Research and Assessment." *Nature 463* (7282): 747-756. Available online at: http://www.nature.com/nature/journal/v463/n7282/full/nature08823.html

Nakicenovic, N., et al. 2000. *Special Report on Emissions Scenarios*, a special report of Working Group III of the IPCC, Cambridge University Press, 599. Available online at: http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/index.htm

Prudhomme, C., and H. Davies. 2009. "Assessing Uncertainties in Climate Change Impact Analyses on the River Flow Regimes in the UK. Part 2: Future Climate." *Climatic Change 93* (1): 197-222. Available online at: http://www.springerlink.com/content/k6687g65v363700n/

Quintana Seguì, P., et al. 2009. "Comparison of Three Downscaling Methods in Simulating the Impact of Climate Change on the Hydrology of Mediterranean Basins." *Journal of Hydrology 83* (1-2): 111-124. Available online at: http://pere.quintanasegui.com/coses/quintana-et-al_journal-of-hydrology_2009.pdf

Robertson, A., et al. 2004. "Downscaling of Daily Rainfall Occurrence over Northeast Brazil Using a Hidden Markov Model." *Journal of Climate 17* (22): 4407-4424. Available online at: http://journals.ametsoc.org/doi/abs/10.1175/JCLI-3216.1

Skamarock, W., et al. 2008. "A Description of the Advanced Research WRF Version 3 (NCR technical note). Available online at: http://www.mmm.ucar.edu/wrf/users/docs/arw_v3_bw.pdf

Tadross, M., et al. 2009. "Growing-Season Rainfall and Scenarios of Future Change in Southeast Africa: Implications for Cultivating Maize." *Climate Research 40*:147-161. Available online at: http://www.int-res.com/abstracts/cr/v40/n2-3/p147-161/

UNDP (United Nations Development Programme). 2010. *Mapping Climate Change Vulnerability and Impact Scenarios: A Guidebook for Sub-National Planners*. New York: UNDP. Available online at: http://www.undp.org

Wilby, R., et al. 2004. *Guidelines for Use of Climate Scenarios Developed from Statistical Downscaling Methods*, prepared for consideration by the IPCC at the request of its Task Group on Data and Scenario Support for Impacts and Climate Aalysis (TGICA). Available online at: http://www.ipcc-data.org/guidelines/dgm_no2_v1_09_2004.pdf

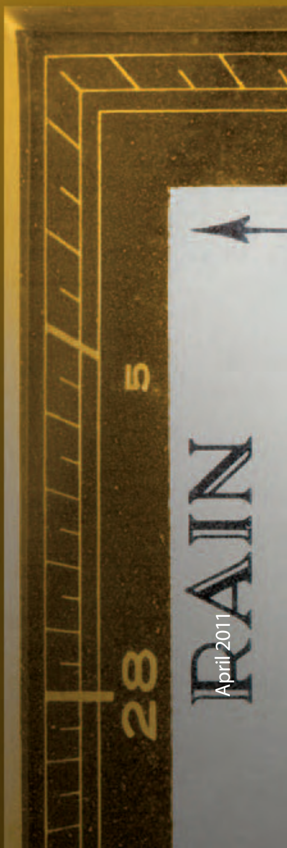
Wilby, R., and I. Harris. 2006. "A Framework for Assessing Uncertainties in Climate Change Impacts: Low-Flow Scenarios for the River Thames, UK." *Water Resources Research 42* (2): W02419.

Wilby, R. 2008. "Dealing with Uncertainties of Future Climate: The Special Challenge of Semi-Arid Regions." Paper presented at Proceedings of the Water Tribune: Climate Change and Water Extremes, Expo Zaragoza, Espagne. Available online at: http://www.expozaragoza2008.es/ContenidosAgenda/tda-st6-es-doc2.pdf

Ziervogel, G., and F. Zermoglio. 2009. "Climate Change Scenarios and the Development of Adaptation Strategies in Africa: Challenges and Opportunities." *Climate Research 40* (2-3): 133-146. Available online at: http://www.int-res.com/abstracts/cr/v40/n2-3/p133-146/

United Nations Development Programme
Bureau for Development Policy
Environment and Energy Group
304 East 45th Street, 9th Floor
New York, NY 10017 USA

www.undp.org



April 2011