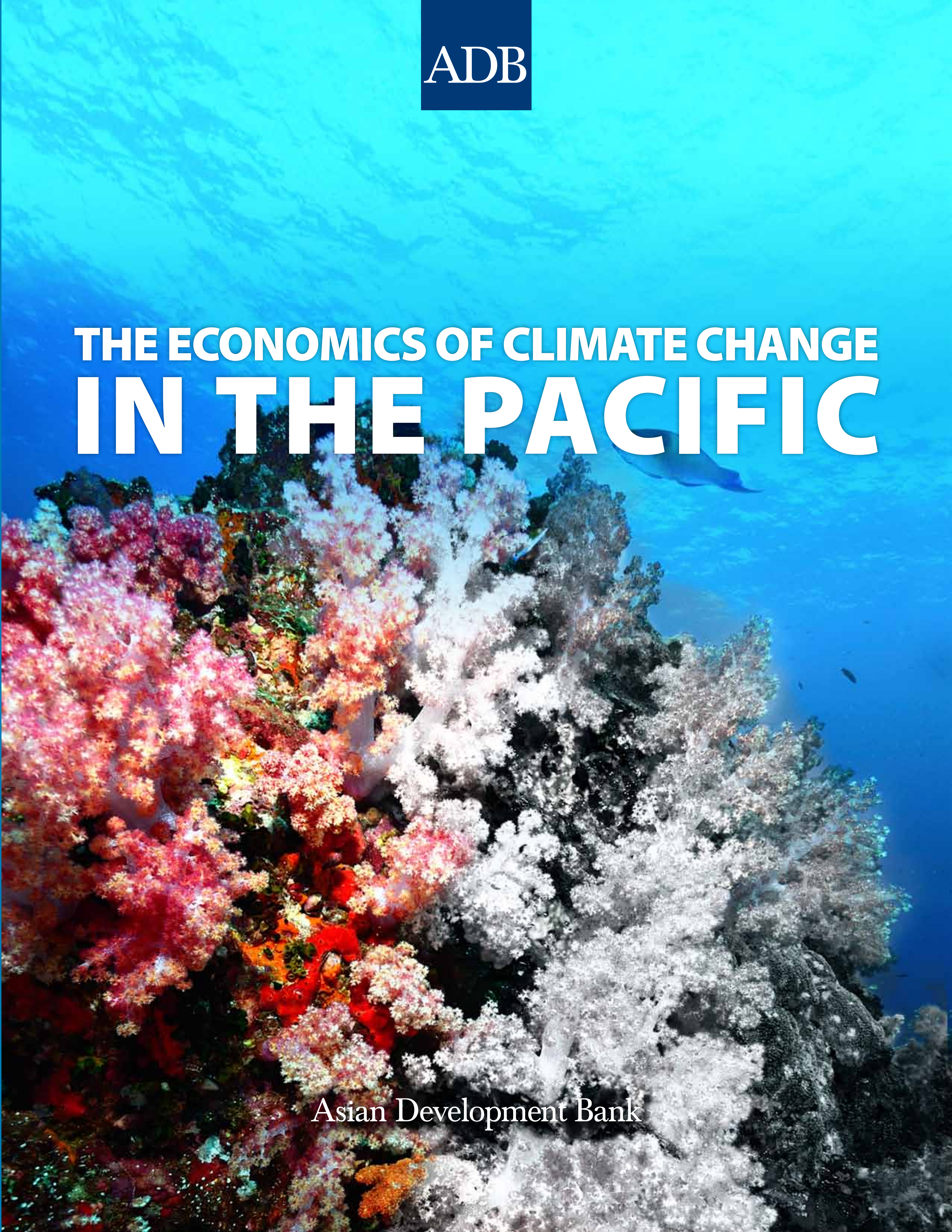
ADB



THE ECONOMICS OF CLIMATE CHANGE IN THE PACIFIC

Asian Development Bank

ADB

THE ECONOMICS OF CLIMATE CHANGE IN THE PACIFIC

Asian Development Bank

© 2013 Asian Development Bank

All rights reserved. Published in 2013.
Printed in the Philippines

ISBN 978-92-9254-318-1 (Print), 978-92-9254-319-8 (PDF), 978-92-9254-328-0 (CD-ROM)
Publication Stock No. RPT136119-2

Cataloging-In-Publication Data

Asian Development Bank.
The economics of climate change in the Pacific
Mandaluyong City, Philippines: Asian Development Bank, 2013.

1. Climate change 2. Economics 3. Pacific region I. Asian Development Bank

The views expressed in this publication are those of the authors and do not necessarily reflect the views and policies of the Asian Development Bank (ADB) or its Board of Governors or the governments they represent.

ADB does not guarantee the accuracy of the data included in this publication and accepts no responsibility for any consequence of their use.

By making any designation of or reference to a particular territory or geographic area, or by using the term "country" in this document, ADB does not intend to make any judgments as to the legal or other status of any territory or area.

ADB encourages printing or copying information exclusively for personal and noncommercial use with proper acknowledgment of ADB. Users are restricted from reselling, redistributing, or creating derivative works for commercial purposes without the express, written consent of ADB.

Note:
In this publication, "$" refers to US dollars.

6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
Tel +63 2 632 4444
Fax +63 2 636 2444
www.adb.org

For orders, please contact:
Public Information Center
Fax +63 2 636 2584
adbpub@adb.org

Printed on recycled paper

CONTENTS

TABLES, FIGURES, AND BOXES

Tables

Figures

Boxes

ABBREVIATIONS

20C3M	20th Century Climate in Coupled Models
ADB	Asian Development Bank
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
°C	degree Celsius
CIF	Climate Investment Fund
CCAM	Conformal Cubic Atmospheric Model
CCIP	Climate Change Implementation Plan for the Pacific
Cm	centimeter
CMIP5	Coupled Model Intercomparison Project Phase 5
CRU	Climate Research Unit
DAI	dangerous anthropogenic interference
DEM	Digital Elevation Model
DMC	developing member country
DSSAT	Decision Support System for Agro-technology Transfer
ENSO	El Niño-Southern Oscillation
EOF	empirical orthogonal function
FSM	Federated States of Micronesia
FUND	Climate Framework for Uncertainty, Negotiation and Distribution
GCMs	general circulation models
GDP	gross domestic product
GISST	global sea-ice and sea-surface temperature
HTM	Hamburg Tourism Model
IAMs	integrated assessment models
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
km	kilometer
km^2	square kilometer
MAC	marginal abatement cost
mm	millimeter
NAPA	National Adaptation Programme of Action
NCSA	National Capacity Self-Assessment
PAGE	Policy Analysis of the Greenhouse Effect
PCCP	Pacific Climate change Program
PCRAFI	Pacific Catastrophic Risk Financing Initiative
PNG	Papua New Guinea
PPCR	Pilot Program for Climate Resilience
ppm	parts per million
PRC	People's Republic of China
RCM	regional climate model
RCP	representative concentration pathways
REDD	Reducing Emissions from Deforestation and Forest Degradation
RegCM3	Regional Climate Model Version 3
RMI	Republic of the Marshall Islands
SLR	sea-level rise
SPCR	Strategic Program for Climate Resilience
SRES	Special Report on Emissions Scenarios
SST	sea-surface temperature
TAR	Third Assessment Report
UNFCCC	United Nations Framework Convention on Climate Change
WPWP	Western Pacific Warm Pool

FOREWORD

Climate change is a serious threat to poverty alleviation and development efforts in the Pacific. The physical, social, and economic characteristics of the Pacific countries make them highly vulnerable to the foreseen intensification of storm surges, cyclones, and rise in sea levels. The marked changes in rainfall patterns and in land and ocean temperatures that now adversely impact the island countries are expected to further aggravate the situation. In a region characterized by extensive growth of rural and urban settlements in coastal areas, none of its countries can hope to remain unaffected by the effects of climate change.

The Asian Development Bank (ADB) conducted this study of the economics of climate change in the Pacific to assist its Pacific developing member countries (DMCs) in adapting to climate risks. After an extensive review of past and ongoing research efforts on climate change, the study focused on identifying and quantifying its economic impacts on the Pacific DMCs. It used the best available methodological tools to assess adverse effects of climate change particularly on agriculture; on fisheries and coral reefs; on tourism; and on the health and well-being of the populace. While the precise nature and extent of climate change in the Pacific countries cannot be predicted with certainty, ADB is confident that the information and knowledge presented in this report will enlighten and encourage the Pacific DMCs to pursue decision-making and development measures that duly consider climate change and its potential consequences.

As embodied in its long-term strategic framework *Strategy 2020*, ADB has incorporated climate change into the core of its operations and of its assistance to its DMCs. ADB is therefore firmly committed to support climate change adaptation efforts through the mainstreaming of adaptation and disaster-risk reduction in national development plans and in country partnership strategies. With this and its ongoing research effort and knowledge dissemination products, ADB thus aims to support achieving a climate-resilient region.

Xianbin Yao
Director General
Pacific Department

Changyong Rhee
Chief Economist
Economics and Research Department

ACKNOWLEDGMENTS

This study on the economics of climate change in the Pacific was conducted by ADB through a technical assistance program, *Strengthening the Capacity of Pacific Developing Member Countries to Respond to Climate Change*. It is cofinanced by the Canadian Cooperation Fund on Climate Change, the Climate Change Fund, and the Asian Clean Energy Fund under its Clean Energy Financing Partnership Facility.

The study is a collaborative effort of the Economics and Research Department (ERD) and the Pacific Department (PARD) of ADB. The study team was led by Mahfuzuddin Ahmed, Principal Climate Change Specialist of the South Asia Department (SARD), and Maria Lourdes Drilon, Senior Natural Resource Economist, PARD. Overall guidance was provided by Juzhong Zhuang, Deputy Chief Economist, ERD; Cyn-Young Park, Assistant Chief Economist, ERD; and Robert Guild, Director of the Transport, Energy and Natural Resources Division, PARD. The findings of the study were synthesized for this report by a team of economists led by Cyn-Young Park, with team members including David Anthony Raitzer, Economist; Suphachol Suphachalasai, Economist now with the World Bank; and Jindra Nuella Samson and Paulo Rodelio M. Halili, Economics Officers, ERD.

The study team is grateful for inputs provided by experts from the Center for Climate Risk and Opportunity Management in Southeast Asia and Pacific (CCROM-SEAP) led by Rizaldi Boer, who was supported by Akhmad Faqih and Agus Buono on climate modeling; by Feril Hartati, Bambang Dwi Dasanto, and Sisi Febriyanti Muin on coastal resources; by Satyanto Krido Saptomo on water resources; and by Adi Rakhman on agriculture. The study team is also grateful to Richard Tol of the University of Sussex for his FUND3.6 model results, and to Chris Hope of the University of Cambridge for his PAGE09 framework.

The economic and technical editing of this report was undertaken by Benoit Laplante and Ronald Miller, the manuscript copyediting by Carlos Llorin Jr. Technical and research support was provided by Leandro Buendia on initial country scoping, and by Sining Cuevas and Roberta Gerpacio in the early stage of the study. The production of the report was assisted by Cecil Caparas, PARD, and Rhommel Rico, ERD. Layout and typesetting was done by Michael Cortes. Administrative support was provided by Ronald Mark Omana, PARD, and Linel Reyes, now with SARD. A team from the Department of External Relations extended expert support for publication.

Finally, the study team gratefully acknowledges the valuable comments and suggestions provided to this study by government officials of the Pacific member countries; by David Sheppard of the Secretariat of the Pacific Regional Environment Program; by Paula Holland of the Secretariat of the Pacific Community; and by the Australian Agency for International Development, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, and the World Bank as ADB's development partners in this undertaking.

EXECUTIVE SUMMARY

Climate change has been identified as one of the critical challenges of this century for the Pacific region. The region's vulnerability arises from its unique geography and environment, the fragility of its economic structure, its distinctive demographics, and the interactions between these different factors. Many of the Pacific developing member countries (DMCs) of ADB have limited agricultural land and high population densities, with their economic activities mostly concentrated on low-lying coastal areas. Rising sea level is thus projected to significantly impact their coastal cities and communities as well as damage infrastructure and human habitats. Moreover, over the past several decades, the Pacific region has experienced increases in annual mean temperature, in variability of rainfall pattern, and in intensity of rainfall events. In the last decades, extreme weather events have also increased in frequency and intensity. Increasing temperatures as well as changes in rainfall patterns are likewise expected to adversely impact the region's water resources and its agriculture and health sectors.

Given these threats to the economic prosperity, stability, and human security of the Pacific DMCs, the region's leaders and policymakers have recognized climate change as a formidable challenge. Tackling this challenge effectively will require (i) detailed assessments of vulnerability and adaptation needs that sufficiently capture local climate as well as socioeconomic characteristics; (ii) economic analyses to assess the impacts of climate change and to guide the selection of adaptation actions at both national and local levels; and (iii) reliable databases and information that must underlie the conduct of such assessments and analyses.

This study aims to estimate the range of potential economic impacts of climate change for specific sectors and for overall economies of the region under various emissions scenarios. It comprises three components.

The first component, climate modeling, presents a high-resolution simulation of future climate over the Pacific region by dynamically downscaling global climate data using a regional climate model to generate locally relevant climate information. This component mostly relies on the use of general circulation models and climate downscaling using a regional climate model. The second component, sector impact assessment, quantifies the potential sectoral impacts of climate change in the Pacific on agriculture, fisheries, tourism, coral reefs, and human health. Finally, the third component, economic impact assessment, employs an economic modeling framework that integrates a set of climate projections and physical impacts to provide estimates of the potential economic impact of climate change for a given area.

While the study covers all of the Pacific DMCs, specific results are presented for Fiji, Papua New Guinea (PNG), Samoa, Solomon Islands, Timor-Leste, and Vanuatu.

Climate Change

Annual mean temperature is projected to rise in the Pacific relative to that of the 1981-2000 period. Most countries, or particular areas within countries, would experience up to a 1.8°C rise by 2050 under a medium emissions scenario. By 2070 under the same scenario, Fiji and Samoa are projected to experience a temperature rise of approximately 2°C on average from the 1990 level. PNG, Solomon Islands, Timor-Leste, and Vanuatu are expected to experience a temperature increase of more than 2.5°C on average by 2070, with some areas in these countries experiencing an increase of nearly 3°C in the same period relative to the 1990 level.

The analysis also suggests a significant increase in the frequency of both El Niño and La Niña events in the future. In general, these would be accompanied by an intensification of extreme weather events, extreme temperature, extreme wind, and extreme rainfall. However, cyclone frequency is generally projected to decline. On balance, weather risk may increase or decrease depending on location. High-range estimates suggest all the Pacific DMCs except Kiribati face a sea-level rise of more than 1.0 meter by 2100 under the medium emissions scenario.

Sector Impact Assessment

Overall, global warming is expected to negatively impact crop productivity in the Pacific. The largest yield losses are projected for sweet potato in PNG and the Solomon Islands, with losses in excess of 50% of yield for the former by 2050 under the medium emissions scenario. For sugarcane, losses would be relatively small in 2050, but would rise in Fiji by 2070 to a more substantial 7% to 21%. Maize would have moderate losses of 6% to 14 % in Timor-Leste and Vanuatu by 2050, with a rise to 14% to 17% by 2070 in the former. Results also show cassava and taro would be significantly impacted. Rainfed agriculture appears to be particularly vulnerable to the impacts of climate change.

Fisheries are also likely to be adversely impacted. Under a high emissions scenario, catches of skipjack tuna for the western Pacific are estimated to decline by an average of more than 20%, and for PNG by as much as 30%. Across the entire region, total catch is projected to decrease by 7.5% under the same scenario by 2100. For bigeye tuna, small decreases in catch (usually less than 5%) are projected by 2035. Catches are projected to decrease by 10% to 30% for many Pacific DMCs under the high emissions scenario in 2100.

Climate change would likely also impact tourism, which is another key economic sector of the region. As the world warms up, the Pacific region as a whole would become a less attractive tourism attraction and total tourism revenues are projected to fall. By the end of the century, tourist numbers are projected to be approximately one-third lower than in a business-as-usual scenario. Under all climate scenarios, the impact of climate change would be to reduce tourism revenues by 27% to 34% for the Pacific region as a whole.

Both the loss of fisheries and tourism are related to the projected impacts of climate change on coral reefs. Mass coral bleaching due to thermal stress has already occurred in the Pacific region and is expected to recur with the foreseen increases in future sea temperatures. The estimate of present coral area in the Pacific in 2000 is around 80% of what would have been in the absence of thermal stress (in the pre-industrial era). The analysis indicates that the Pacific would experience an increase in thermal stress that would likely result in a significant decline in coral reef cover, from 88% in the base year (1995) to 55% in 2050 and 20% in 2100.

Finally, climate change would adversely impact human health in the Pacific region. The human health costs are valued in terms of forgone income as well as additional expenditure for treatment of illnesses. Mortality and morbidity costs together are expected to reach 0.8% of GDP by 2100 under a high emissions scenario. Most of the estimated health costs would arise from respiratory disorders, followed by malaria, and deaths from tropical storms. By 2100, approximately 80% of total mortality cost is projected to be caused by respiratory disorders due to climate change, and 14% by vector-borne diseases, particularly malaria.

Economic Impact Assessment

Overall, the results suggest net negative impacts of climate change for the Pacific by 2050 in all scenarios regardless of which model is used. Losses are projected to rise over time under all scenarios, and would be largest with high emissions scenarios. If the world were to stay on the current fossil-fuel intensive growth model (the business-as-usual scenario), total climate change cost in the Pacific is estimated to reach 12.7% of annual GDP equivalent by 2100. Even under a low emissions scenario in which the global economy is assumed to restructure itself to be service-oriented, the economic loss would still reach 4.6% of the region's annual GDP equivalent by 2100. If the atmospheric concentration of greenhouse gases were to reach 450ppm and thus maintain global warming at approximately 2°C, the economic cost would be smaller but still would reach between 2% and 3% of GDP by 2100. The results suggest that PNG would experience the most significant losses from projected climate change, reaching 15.2% of its GDP by 2100, followed by Timor-Leste at 10.0%, Vanuatu, 6.2%, Solomon Islands, 4.7%, Fiji, 4.0%, and Samoa, 3.8%.

The negative effect on agriculture contributes the most to the total economic cost of climate change in the Pacific—approximately half of total economic cost amounting to 5.4% of GDP in 2100 under a high emissions scenario. Cooling cost follows second. A warmer climate would put pressure on the rapidly rising energy demand for space cooling in households and buildings around the Pacific. When income and population growth in the urban areas are considered, the cost of cooling is estimated to reach $1,017 million or 2.8% of the region's annual GDP equivalent by 2100. Economic impacts in the coastal areas would also be significant. The impacts in the coastal areas would consist of three components: dryland loss, wetlands loss, and forced migration. The total impact in the coastal areas, through all three channels, is projected at $469 million or 1.3% of the region's annual GDP equivalent by 2100.

It should be noted that none of the above estimates includes the potential large cost of rare but catastrophic extreme events.

It is estimated that the Pacific region would require $447 million on average every year until 2050 (approximately 1.5% of GDP) to prepare for the worst case (95th percentile) of climate change under the business-as-usual scenario. The cost could be as high as $775 million or 2.5% of GDP per annum. The cost of adaptation would be significantly lower under lower emissions scenarios. If the world manages to stabilize CO2 concentration below 450ppm, the adaptation cost is expected to be as low as $158 million or 0.5% of GDP per annum during the same period.

Policy Recommendations

Climate change is not a stand-alone environmental issue but a development agenda that the Pacific DMCs need to give high priority. If not adequately addressed, climate change could overturn the region's development achievements. Important policy considerations include the following:

1. **Mainstreaming climate change actions in development planning is crucial to minimize the impacts of climate change.**

   Mainstreaming climate change actions requires merging new development efforts into a comprehensive policy framework that combines various sector approaches, policies, and strategies for achieving climate-resilient and sustainable development. To serve as guiding principles, adaptation to climate change needs to be well-integrated into a comprehensive policy framework. Such climate mainstreaming should be harmonized with existing climate change programs and policies at both the sectoral and national level.

2. **A forward-looking adaptation strategy is key to addressing the multitude of climate change impacts, with low-regret options and built-in flexibility as a basis for a robust adaptation pathway.**

   To effectively address a wide range of uncertain climate outcomes, national development planning efforts should consider adopting a forward-looking adaptation strategy. Such a strategy needs a thorough appraisal and screening of all available and potential adaptation measures to enable the country at risk to choose which of them are the most socially acceptable, most economically viable, most technically feasible, and most compliant with local development priorities.

   A robust adaptation pathway is one that allows for flexibility in dealing with future climate vulnerability in the face of newly available evidence. It requires the continued monitoring and review of ongoing climate change measures to avoid locking in long-term investments in potentially inefficient undertakings.

3. **Adopting a risk-based approach to adaptation and disaster-risk management can help prioritize climate actions and increase the cost-efficiency of adaptation measures.**

   The region's disaster-risk management must be better aligned with climate change risks. This would require (i) appropriate policies, technical skills, and institutional setups to integrate and mainstream climate actions and disaster-risk management into development planning; (ii) establishment in the communities of a cross-sectoral, cross-agency coordination system for disaster risk management and climate change adaptation; and (iii) improved data and knowledge to assess climate, disaster, and fiscal risks.

4. **Climate proofing infrastructure can help improve long-term sustainability.**

   Climate proofing should be considered as early as possible in the project design stage. Although climate proofing could increase the upfront costs of the infrastructure projects, such higher costs could be economically justified by lower total life cycle costs over the long lifetime of most infrastructure and by the high probability of climate-related damage in the Pacific.

5. **Improving knowledge and the capacity to deal with climate uncertainties is a key issue for the Pacific DMCs.**

   Fine-scaled models and various decision-support tools can help provide the authorities of the Pacific DMCs with valuable location-specific information and analysis that can capture local characteristics of climate change impacts. This, in turn, will allow for more effective climate-risk assessment to support development planning and decision making, ranging from public investment in infrastructure to actions at the household and community levels.

To enhance the value and accuracy of climate information, there is a need to further develop climate observation networks and to expand tools and models for climate-risk assessment. These efforts should be complemented by a properly designed capacity-building and awareness-raising program for disseminating climate change information and impact-assessment tools.

6. Improved access to climate finance is critical for ensuring continued economic growth and development for the Pacific DMCs.

Regardless of the climate scenario and modeling approach, the estimated cost of climate change adaptation is considerable. The Pacific DMCs will require substantial increases in investment, supported as appropriate with financial and technical support from the international community.

7. Successful adaptation efforts require strong cooperation and coordination among multiple partners within and beyond the Pacific region.

ADB's *Climate Change Implementation Plan for the Pacific* aims at scaling up climate adaptation efforts based on consensus-building among multiple partners, and assisting capacity development of the Pacific DMCs to effectively respond to climate change. Specifically, the CCIP aims to enhance the climate resilience of the Pacific countries and mitigate the impacts of natural disaster risks through four major measures: (i) mainstreaming adaptation policies, plans, programs and projects into development planning; (ii) strengthening information systems and capabilities to facilitate the adaptation process; (iii) establishing the legal, regulatory, and institutional framework to support policy implementation, and (iv) promoting access to affordable financing for climate-resilient development.

Chapter 1
INTRODUCTION

The 14 Pacific developing member countries (DMCs) of the Asian Development Bank (ADB) consist mostly of small and geographically isolated islands, some of them low-lying atolls, in the Pacific Ocean; each of the islands has a limited resource base and fragile biodiversity. The countries are the Cook Islands, Fiji, Kiribati, Republic of the Marshall Islands (RMI), the Federated States of Micronesia (FSM), Nauru, Palau, Papua New Guinea (PNG), Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, and Vanuatu. Their combined population of approximately 10.7 million is of diverse ethnicity and culture.

For the Pacific region as a whole, climate change has been identified as one of the critical challenges of this century. The region's vulnerability to climate change arises from its unique geography and environment, the fragility of its economic structure, its distinctive demographics, and the interactions between these different factors. Many of the Pacific DMCs have limited agricultural land and high population densities, with their economic activities mostly concentrated on low-lying coastal areas. Rising sea level is thus projected to significantly impact their coastal cities and communities as well as damage infrastructure and human habitats. Moreover, over the past several decades, the Pacific region has experienced increases in annual mean temperature, in variability of rainfall pattern, and in intensity of rainfall events.[1] In the last decades, extreme weather events have also increased in frequency and intensity.[2] Increasing temperatures as well as changes in rainfall patterns are likewise expected to adversely impact the region's water resources and its agriculture and health sectors.

Given these threats to the economic prosperity, stability, and human security of the Pacific DMCs, the region's leaders and policymakers have recognized climate change as a formidable challenge. These island-nations have limited capacity to adapt and respond to climate change, however, and the region as a whole has scant resources to handle the complex financing arrangements for climate change activities.

This study therefore aims to support the Pacific DMCs in developing their climate change adaptation plan and strategy. Its core concept is that current and future plans aimed at improving living standards and achieving sustainable development should factor in climate change and its potential consequences. Policy and decision-making need to clearly take into account the reality of climate change, the costs of inaction, and the benefits of adaptation actions. For this purpose, the study provides climate information that can be used to support adaptation actions under various climate scenarios. The study presents estimates of the

[1] See Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (2011).

[2] In the 1990s, extreme weather events cost the Pacific region more than $1 billion. In 1990 and 1991, Cyclones Ofa and Val alone cost Samoa $440 million—more than the country's gross domestic product (GDP). Cyclone Heta in Niue caused $27 million in damages (25% of its GDP). In early 2005, the Cook Islands experienced five cyclones within 5 weeks—four of which were of Category 5. In February 2008, Fiji lost $32 million to Cyclone Gene (ADB 2011 and McKenzie et al. 2005).

possible impacts of climate change on significant sectors of the region, assesses the economy-wide impacts of climate change, and quantifies funding needs for climate change adaptation.

One other major aim of this study is to contribute to the growing literature on climate change impacts in the context of the Pacific region. Climate science in its current state cannot accurately predict future climate at either the global or the regional level. Nonetheless, this study can help forearm the Pacific DMCs with the knowledge to prepare for climate change impacts and to identify adaptation actions for mitigating them. As discussed in detail in this study, such adaptation actions should be systematically developed and implemented on the basis of (i) detailed assessments of vulnerability and adaptation needs that sufficiently capture local climate as well as socioeconomic characteristics; (ii) economic analyses to assess the impacts of climate change and to guide the selection of adaptation actions at both national and local levels; and (iii) reliable databases and information that must underlie the conduct of such assessments and analyses.

The report consists of the following chapters:

Chapter 2 – Overview of the vulnerability of the Pacific DMCs to climate change in relation to their geographic and economic characteristics.

Chapter 3 – Methodology and modeling framework used for the study.

Chapter 4 – Projected future climate change and climate extremes in the Pacific region based on selected emissions scenarios and a downscaling exercise, along with a discussion of the biophysical consequences of climate change.

Chapter 5 – Assessment of the sectoral implications of climate change in the Pacific, with a focus on agriculture (for selected main commercial and staple food crops), fisheries, tourism, coral reefs, and human health.

Chapter 6 – Presentation of a macro-economic perspective that quantifies the economic costs of climate change at the national and regional levels, and suggests estimates of adaptation funding needs.

Chapter 7 – Summary of the key findings and their policy implications.

By making climate change adaptation truly integral to their policy-making and decision-making processes, the Pacific island-nations could plan against the adverse impacts of climate change and continue their efforts to achieve poverty eradication and sustainable development for the region.

References

Asian Development Bank (ADB). 2011. *Food Security and Climate Change in the Pacific: Rethinking the Options*. Pacific Studies Series, Manila.

Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation. 2011. *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview*.

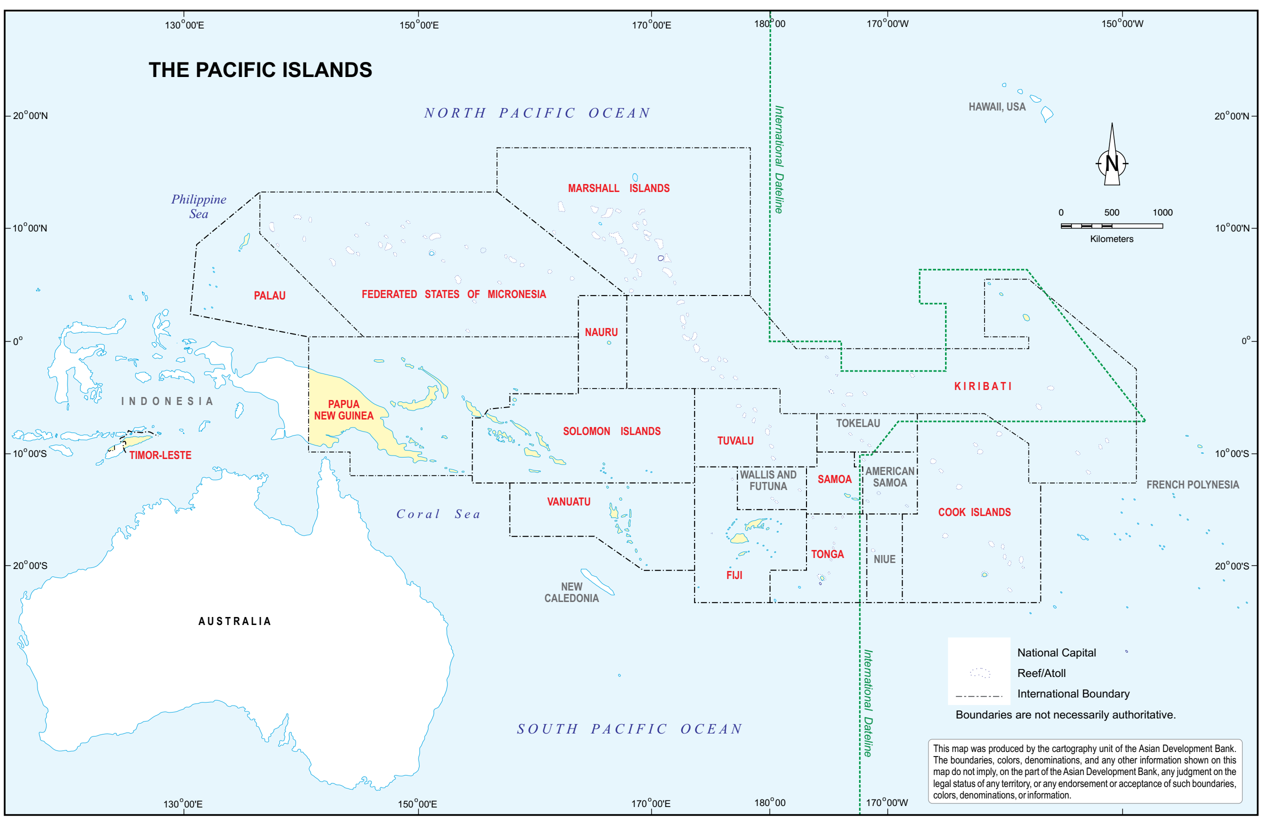
McKenzie, D., Jackson, J. and K. Priestley. 2005. Thermal structure of oceanic and continental lithosphere. *Earth and Planetary Science Letters*. 233. 337–349.

Chapter 2

VULNERABILITY OF THE PACIFIC NATIONS TO CLIMATE CHANGE

In recent years, numerous assessments have been made of the vulnerability of the Pacific nations to projected climate change, including the assessment contained in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC 2007). This chapter aims to provide a succinct overview of the key factors identified thus far to be contributing to this vulnerability.

Figure 2.1: Map of the Pacific Region



12-3960 AV

I. Overview of Geographic and Environmental Features

The unique geography and environment of the Pacific Region make it highly vulnerable to climate change.

The Pacific DMCs are scattered across a large area of the South Pacific Ocean covering more than 30 million square kilometers (km^2) (Figure 2.1). The region's sovereign zone stretches up to 10,000 kilometers (km) from east to west, and 3,000 km from north to south. It covers a total land area of approximately 528,090 km^2 with PNG representing 88% of the land area. Many of the island-nations are small, occupying less than 1,000 km^2; Nauru is the smallest at 22 km^2 (Table 2.1).

With its many islands, the region has an extensive coastline of around 25,000 km that represents approximately 3% of the total world coastline; it is longer than the coastlines of the People's Republic of China (PRC) and India combined (ADB 2004). More than half of the region's population lives within a

Table 2.1: Geographic and Topographic Profiles of Pacific Countries

Pacific DMCs	Total area (km^2)	Geographic location	Topography and land features
Cook Islands	240	21 14 S 159 46 W	15 islands with 7 low-lying in northern part while 8 are elevated; sparsely populated, coral atolls; most of the populace live in fertile volcanic isles.
Fiji	18,270	18 00 S 175 00 E	Includes 332 islands of which approximately 110 are inhabited; mostly mountains of volcanic origin.
Kiribati	811	1 25 N 173 00 E	Mostly low-lying coral atolls surrounded by extensive reefs; 21 of the 33 islands are inhabited; Banaba (Ocean Island) is one of the three great phosphate rock islands in the Pacific Ocean.
RMI	181	9 00 N 168 00 E	Two archipelagic island-chains of 30 atolls and 1,152 islands; low coral limestone and sand islands.
FSM	702	7° 46N 151° 84E	4 major island groups with a total of 607 islands; islands vary geologically from high mountainous islands to low, coral atolls; volcanic outcroppings on Pohnpei, Kosrae, and Chuuk.
Nauru	22	0 32 S 166 55 E	One of the three great phosphate rock islands in the Pacific Ocean; uplifted limestone island with narrow coastal plain; sandy beach rises to a fertile ring around raised coral reefs with phosphate plateau at center.
Palau	458	7 30 N 134 30 E	6 island groups totaling more than 300 islands; they vary geologically from the high, mountainous main island of Babelthuap to low, coral islands usually fringed by large barrier reefs.
PNG	462,840	6 00 S 147 00 E	Mostly mountains with coastal lowlands and rolling foothills; shares island of New Guinea with Indonesia; one of the world's largest swamps along the southwest coast.
Samoa	2,944	13 35 S 172 20 W	Two main islands (Savaii, Upolu) and several smaller islands and uninhabited islets; narrow coastal plain with volcanic, rocky, rugged mountains in interior.
Solomon Islands	28,450	8 00 S 159 00 E	Mostly rugged mountains with some low coral atolls.
Timor-Leste	228	8 50 S 125 55 E	The island is part of the Malay Archipelago and is the largest and easternmost of the Lesser Sunda Islands; mountainous.
Tonga	718	20 00 S 175 00 W	An archipelago of 169 islands (36 inhabited); most of them have a limestone base formed from uplifted coral formation; others have limestone overlying volcanic base.
Tuvalu	26	8 00 S 178 00 E	Very low-lying and narrow coral atolls.
Vanuatu	12,200	16 00 S 167 00 E	A Y-shaped chain of 4 main islands and 80 smaller islands, about 65 of which are inhabited; several of the islands have active volcanoes.
Total	**528,090**		

distance of 1.5 km from the shoreline (IOC/UNESCO, IMO, FAO, UNDP 2011). In smaller countries such as Samoa, up to 80% of the total population lives near the coast (Hay and Wedderburn 2011). Most settlements and infrastructure, including airports and centers of government, are located along the coast, thus exposing them to flooding and storm surges.

With Fiji, the Solomon Islands, and PNG as exceptions, most of the island countries in the Pacific have limited surface water and are highly dependent on rain and groundwater resources for their water requirement. Atoll countries and limestone islands have no surface water or streams and are fully dependent on rain and groundwater. Some of the countries are already experiencing significant declines in freshwater supplies. Among the well-known reasons for the decline are deforestation, increasing water demand, erratic rainfall pattern, saltwater intrusion of groundwater, and increasing water pollution. Projected changes in rainfall pattern, accompanied by increasing saltwater intrusion, make the limited water resources of the islands of the region particularly sensitive to climate change. As noted in IPCC's AR4, water resources in small islands are likely to be seriously compromised (IPCC 2007, Chapter 16).

The Pacific region is home to a rich variety of flora and fauna (ESCAP 2006). In PNG alone, more than 250 species each of mammals, reptiles, and amphibians as well as more than 11,000 species of plants are found. On some islands, 80% or more of the species are found nowhere else on earth. Many species of mammals, birds, plants, reptiles, amphibians, and fishes are already threatened or at risk of extinction. While the region has a remarkably rich and unique set of ecosystems, these systems and the biodiversity they harbor are fragile and threatened. This makes them particularly sensitive to climate change.

II. Demographic and Economic Factors

The Pacific region has a rapidly growing population, taxing resources that may be further pressed by the effects of climate change.

The Pacific region is currently home to approximately 10.7 million people (ADB 2013), with 68% of the total population living in PNG.[3] Over the last 17 years, the region's population had at an average annual growth rate of 2.95%, increasing by 50% over the 1995 level. By comparison, Asia's population as a whole grew at an average annual rate of 1.3% over the same period. The region's population is expected to reach 24 million by 2050, with 17 million in PNG alone (UN 2013).

Rapid population growth creates increasing pressure on a range of resources, including freshwater, food production, and land. The additional stress on resource availability arising from rapid population growth, in combination with the vulnerability to climate change, creates a particularly significant set of risks.

Economic development in the region has been uneven, poverty rates remain high, and many national economies are narrowly based, with large sectors vulnerable to the effects of climate change.

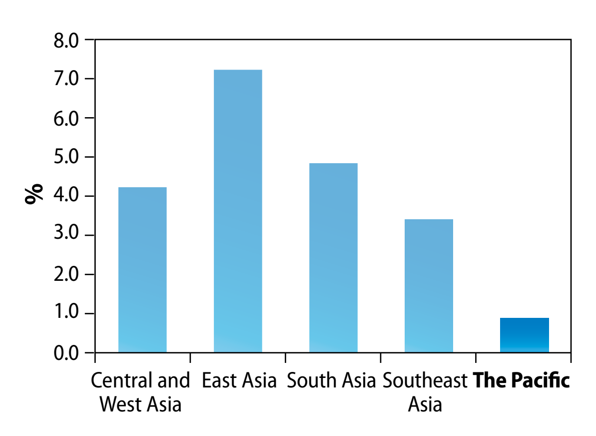
The geography of the Pacific region, with its mostly small countries scattered over a large expanse of ocean, means that the countries of the region are physically isolated from foreign markets. Moreover, their smallness and stage of economic development leave them with relatively limited domestic markets. Although communication in most of the Pacific countries has improved in recent decades, their remoteness remains a major challenge to economic development.

With the exception of Timor-Leste and PNG, which grew over the period 2000–2012 at an annual rate of 5.8% and 4.0%, respectively, economic growth in the Pacific DMCs has been relatively slow in recent years. Per capita annual real GDP growth in the region averaged less than 1% over the period 2000–2012, lower than any other region of Asia (Figure 2.2).

Poverty remains a major challenge. Approximately 35% of the region's population lived below the poverty line in 2010 (defined as $1.25 per day), with 58% of the population having a daily income below $2.00 (World Bank 2013). While

[3] PNG, Fiji, and Timor-Leste together account for approximately 88% of the population of the Pacific region (ADB 2013).

Figure 2.2: Average Annual Growth in Real GDP Per Capita, 2000–2012 (%)



Source: World Bank WDI, accessed 11 October 2013.

poverty rates have generally been falling over the last 20 years, the decline has been slow and uneven. Further, the total number of poor people has risen over most of the period, falling only in recent years. The prevalence of poverty and the slow rate at which it is being alleviated contribute to the vulnerability of the region to climate change.

Climate change will challenge key drivers of economic development in most Pacific countries.

Most of the Pacific DMCs are highly dependent on the services sector, which contributed to between 27% of GDP (in PNG) and 86% (in the Cook Islands) in 2011 (Table 2.2).

Tourism is a central contributor to the region's economy and is the major source of foreign exchange for many of the Pacific countries. The sector accounted for approximately 56% of GDP in Palau in 2010, for 44% in the Cook Islands, for 34% in Vanuatu, and for 23% in Fiji. Between 1990 and 2011, total international tourist arrivals in the region more than doubled from half a million visitors to approximately 1.3 million visitors, with Fiji remaining a favorite destination with 675,000 tourist arrivals in 2011 (ESCAP 2012). While the tourism sector represents an important source of local income, it is heavily dependent on the region's unique geography and environment, including its beaches, coral reefs, and marine resources. These coastal resources are particularly susceptible to the negative effects of climate change.

Agriculture is also economically important, contributing to 29% of GDP in PNG, 28% in FSM, and 26% in Kiribati.

Being sectors dependent on natural resources, tourism and agriculture together account for a dominant share of overall economic activity (Table 2.2). It reaches 62% of GDP in Palau, 58% in Vanuatu, and 49% in the Cook Islands. Moreover, industrial activities mainly involve the processing of agricultural and natural-resource products like fish, pearls, and shells as well as wood (Table 2.3). With its strong dependence on agriculture and natural resources, the industrial sector itself is therefore also vulnerable to climate change.

Table 2.2: Share of Pacific Economies Dependent on Natural Resources (GDP Share by Sector, %)

Economic Indicators	Cook Islands	Fiji	Kiribati	RMI	FSM	Palau	PNG	Samoa	Timor-Leste	Tonga	Vanuatu
Agriculture	4.6	12.1	26.3	15.0	27.8	5.5	29.1	9.8	3.3	18.8	23.9
Industry	9.0	22.0	8.2	13.1	9.1	8.4	44.2	27.9	85.6	21.1	10.1
Services	86.4	65.9	65.5	72.0	63.2	86.1	26.7	62.3	11.1	60.1	66.0
of which international tourism receipt	44.4	23.4	2.9	2.0	8.4	56.0	0.03	20.2	2.6	5.8	34.1
Tourism plus agriculture	49.0	35.5	29.2	17.0	36.2	61.5	29.1	30.0	5.9	24.6	58.0
Employment in agriculture	4.3	1.3	2.8	12.0	52.2	7.8	72.3	35.4	50.8	27.9	60.5

Note: GDP data is for 2011 except for Palau, PNG, Samoa, Tonga, and Tuvalu, which is 2012 data. Employment data is based on most recent year available. Tourism data is for the year 2010 except for Kiribati and Tonga (2005). Nauru and Tuvalu are not included in the table owing to the absence of tourism data. Solomon Islands lacks GDP shares data. Sources: ADB (2013) and ESCAP (2012) for tourism data.

Table 2.3: Key Activities in Economic Sectors of the Pacific Region

Country	Agriculture	Industry
Cook Islands	Fruit processing, copra, citrus, coffee	Fish processing, pearls and pearl shells, handicrafts, mining, clothing
Fiji	Sugar, copra	Timber, cottage industry, fish and food processing, gold, clothing
Kiribati	Copra	Fish processing, handicrafts
RMI	Copra, coconut oil	Fish processing, handicrafts (shells, wood, pearls)
FSM	Bananas, black pepper	Fish processing, handicrafts (shells, wood, pearls), construction, garment
Nauru	Coconut products	Phosphate mining
Palau	Coconuts, bananas, root crops	Fish processing, handicrafts
PNG	Copra, palm oil, coffee, cocoa	Timber, plywood and wood-chip production, fish processing, mining, crude oil, construction
Samoa	Coconut oil and cream, copra, beer	Timber, fish processing
Solomon	Palm oil, cocoa, copra	Timber, fish processing
Timor-Leste	Corn, rice, coffee	Coffee processing, sandalwood, traditional cloth (tais) weaving, furniture-making
Tonga	Squash, vanilla, root crops, coconut oil	Fish processing
Tuvalu	Copra	Fish processing, stamps/coins
Vanuatu	Coconut, coffee, cocoa	Wood processing, fish processing

Source: ESCAP 2006.

The Pacific region has a narrow resource base particularly for agricultural production, which is already stressed due to the increasing population.

The Pacific region had only 2.47 million hectares of land devoted to agricultural production in 2011. Almost half of the total agricultural area is found in PNG, while Fiji and Timor-Leste each have more than 14% of the total agriculture area in the region (FAO 2013).

Some of the Pacific DMCs have already devoted much of their limited land area to agriculture (Table 2.4). RMI and Tuvalu have already used more than 60% of their total land area for agricultural production, while in Kiribati and Tonga the figure is above 40%. As such, in some of the countries of the region, there is already considerable stress on the supply of arable land just to meet current food requirements.

Table 2.4: Area of Agricultural Land in the Pacific Countries, 2011

Country	Area devoted to agriculture ('000 ha)	Area devoted to agriculture (% of total area)
Cook Islands	3	12.5
Fiji	427	23.4
Kiribati	34	41.9
RMI	13	72.2
FSM	95	30.1
Nauru	0.4	20.0
Palau	5	10.8
PNG	1,190	2.6
Samoa	35	12.4
Solomon	91	3.25
Timor-Leste	360	24.2
Tonga	31	43.1
Tuvalu	1.8	60.0
Vanuatu	187	15.3
Total	**2,474**	**4.6**

Source: FAOSTAT accessed 11 October 2013.

III. Vulnerabilities to Specific Aspects of Climate Change

Increasing temperatures have already affected coral reefs and marine life in the Pacific region. This situation is projected to worsen as surface temperature continues to rise.

The Pacific coastline, which holds a diverse variety of coral reefs, mangroves, and sea grasses, is considered to have the largest coral-reef area and the highest marine biodiversity in the world. This marine environment contains enormous and largely unexplored resources, including the largest tuna fishery, the deepest oceanic trenches, and the healthiest remaining populations of threatened marine species, particularly whales, sea turtles, dugongs, and saltwater crocodiles.

Coral reefs are of crucial importance, for they serve not only as habitat for marine species but also as a central attraction for the tourism industry. Coral-reef systems play an important role in maintaining beaches and coastal land against the eroding forces of storms and rising seas. They also provide essential resources for construction materials and serve as raw materials for the handicraft industries.

Serious coral-reef bleaching and decline in the health of coral reefs have occurred in many parts of the region, resulting in a decline in marine life and diversity as well as shifting in tuna stocks. An increase in coral bleaching was already being experienced by Tonga by the year 2000 (Salvat 2002), and the same experience along with habitat loss is predicted for the Cook Islands[4] and PNG (Jones 2004).

The Pacific region is a rich source of fish species that are sensitive to changes in sea-surface temperature. For instance, the distribution of tuna fisheries is affected by the location of the western pacific warm pool (WPWP), an area of warm surface water that provides a home for virtually all tuna species. Thus, these fisheries may be seriously affected by warmer water resulting from climate change (Bell et al. 2011).

Over recent decades, the Pacific region has experienced a significant increase in the number, intensity, and impact of extreme weather events.

Most of the extreme weather events that occur in the Pacific region are caused by tropical cyclones and storm surges as well as by events related to El Niño and La Niña. These extreme events have increased in frequency and intensity in recent decades. Since 1970, in particular, the number of category 4 and 5 tropical storms in the South Pacific region has doubled, with the level of activity of tropical cyclones most active during El Niño years (IPCC 2007). In 2005, five tropical cyclones hit the Cook Islands within a five-week period, severely devastating coconut plantations.

The El Niño events have also become stronger and more frequent. Between 1961 and 2003 in the South Pacific region, particularly in years following the onset of El Niño, significant increases in the annual number of hot days and warm nights as well as significant decreases in the annual number of cool days and cold nights were observed (Manton et al. 2001; Griffiths et al. 2003).

The extreme events that the Pacific region is experiencing have resulted in severe water shortages, coastal erosion and inundation, decline in agricultural production, forest degradation, and disease outbreaks. The geographic, demographic, and economic characteristics of the countries of the Pacific make them particularly vulnerable to these extreme events. In particular, the extensive coastline of the countries in the region as well as their generally low elevation makes them highly vulnerable to coastal flooding and storm surges. The concentration of their population and of government and economic infrastructure in coastal areas also increases the potential for critical storm damage.

The precarious freshwater supply of many of the Pacific countries is exposed and vulnerable to significant storm impacts. For example, typhoons and storm surges in the RMI have increased the salinity and contamination of groundwater. In Vanuatu, rainwater storage facilities have been destroyed by typhoons. Increased frequency or greater intensity of extreme weather events, or both, will put an additional burden on already stressed water resources. Such increase could also exacerbate coastal erosion and inundation as well as the destruction of coral-reef systems and mangrove forests, as in the case of the RMI where the health

[4] See www.spc.int/climate change/fisheries/assessment/chapters/summary/3-cook.pdf.

of its mangroves is already affected. In the Cook Islands, an increase in heavy precipitation events could worsen its erosion problem, and a potential increase in wave overtopping could flood low-lying areas. In FSM, wave and storm surges have increased coastal flooding and coastal erosion that could lead to greater loss of land and the destruction of major historic and cultural sites. In Samoa, heavier rains are expected to increase flooding of the low-lying flat lands. In Tonga and Tuvalu, storm surges, high seas, and gale-force winds in combination with projected mean sea-level rises are expected to increase the incidence of wave overtopping or inundation of low-lying areas.

The IPCC (2007) has predicted that if the intensity of tropical cyclones continues to increase, significant damage to food crops and infrastructure is likely to occur in the Pacific region. In Fiji, in particular, it is projected that the increase in frequency and intensity of extreme events could lead to a significant drop in yield of major crops such as sugarcane. In the Solomon Islands, any increase in cyclone frequency and severity could have serious impacts on palm oil production. Indeed, the aftermath of strong tropical cyclones could turn a small island country into a total food-importer for months or even years.

Sea levels have already risen in the Pacific Region and are projected to continue rising. Effects on coastal erosion, flooding and loss of agricultural land are expected to worsen.

During the 20th century, the average mean relative sea-level around the whole Pacific region increased at the rate of 0.77 millimeter per year (mm/yr) (Mitchell et al. 2001 and IPCC 2007). In recent years, sea-level rise in the Pacific region has increased coastal erosion and inundation, and contributed to the loss of productive agricultural lands.

Rising sea levels have already aggravated coastal erosion and inundation in the region. In the Cook Islands, for example, the main island of Rarotonga was reshaped by serious coastal erosion that destroyed its coral reefs. In Tonga, rising sea levels severely eroded the beaches and inundated coastal villages. In the RMI, the Majuro Atoll is projected to lose 80% of its land if the sea level rises by 50 centimeters (cm), a level consistent with forecasts for the end of this century. In Palau, a significant portion of the land area could be lost over the next 100 years as sea levels rise and strong storms continue to batter the islands.

Sea-level rise has already impacted freshwater supply in many countries of the Pacific Region and its effects are expected to increase significantly.

Sea-level rise combined with changes in precipitation will impact water supply and groundwater from well fields near the coastal regions (Rasmussen et al. 2013). The direct impact of sea-level rise on water resources arises from: (1) new and accelerated coastal erosion; (2) more extensive coastal inundation and higher sea flooding; (3) increases in the landward reach of sea waves and storm surges; (4) seawater intrusion into surface water and coastal aquifers; and (5) further encroachment of tidal waters into estuaries and coastal river systems (Hay and Mimura 2005).

Shallow coastal aquifers and groundwater in low-lying areas are at great risk for salinity intrusion. Salinization of coastal aquifers due to sea-level rise would reduce ground water recharge, resulting in a decrease in fresh groundwater resources. Decreases in precipitation, coupled with sea-level rise, are expected to reduce harvestable volumes of water and sizes of narrow fresh water lenses (Kumar 2012).

Saltwater intrusion due to storm surges and sea-level rise would be most severe in small islands, because large proportions of the land mass of these islands are at low elevations but the intrusion could be minor for larger and higher lands (e.g., Fiji and Samoa), as a consequence of higher rainfall (Rozell and Wong 2010, Mimura 1999, Keener et al. 2012). The combined effects of potential changes to storm and wave events and sea-level rise may cause vital freshwater lenses to be washed over and degraded in Pacific atolls, such that freshwater supplies become salinized. In Nauru, Samoa, Solomon Islands, and Vanuatu, for instance, any rise in sea level, combined with a loss of land area from erosion, could increase salt-water intrusion of freshwater and groundwater resources. This potentially could render atolls in the region uninhabitable (Terry and Chui 2012).

As noted in the IPCC's AR4, such characteristics of small islands as limited size, rapid population growth, and proneness to natural hazards make them particularly vulnerable to the effects of climate change, sea-level rise, and extreme events. In most cases, a small island country would have low adaptive capacity and limited resources to adapt to climate change. As a result, it is imperative for the country to anticipate and prepare for its possible impacts.

A methodological approach for modeling those impacts is presented in the next chapter.

References

Asian Development Bank (ADB). 2004. *Pacific Region Environmental Strategy 2005–2009*. Volume 1: Strategy Document. Manila.

______. 2013. *Key Indicators for Asia and the Pacific 2013: Asia's Economic Transformation-Where to? How and How Fast?* Manila.

Bell, J.D., Johnson, J.E. and A.J. Hobday (eds). 2011. *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Secretariat of the Pacific Community, Noumea, New Caledonia.

Food and Agriculture Organization (FAO). 2013. FAOSTAT at http://faostat.fao.org/ site/291/ default.aspx (accessed 11 October 2013).

Griffiths, G.M., Salinger, M.J., and I. Leleu. 2003. Trends in extreme daily rainfall across the South Pacific and relationship to the South Pacific convergence zone. *International Journal of Climatology*. 23. 847–869.

Hay, J.E. and N. Mimura. 2005. Sea-level rise: implications for water resources management. *Mitigation and Adaptation Strategies for Global Change*. 10. 717–737.

Hay, W. and S. Wedderburn. 2011. "Ridge to Reef" Management Approaches: Addressing Interactions in Samoa's Coastal Zone. *Inprint*. 2011/3. 40–44.

IOC/UNESCO, IMO, FAO, UNDP. 2011. *A Blueprint for Ocean and Coastal Sustainability*. Paris: IOC/ UNESCO.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007. The Physical Science Basis. Summary for Policymakers*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Secretariat. Switzerland.

Jones, G.P. 2004. *Coral Decline Threatens Fish Biodiversity in Marine Reserves*. School of Marine Biology and Aquaculture, James Cook University, Townsville, Australia.

Keener, V. W. et al. (eds.). 2012. *Climate Change and Pacific Islands: Indicators and Impacts*. Report for The 2012 Pacific Islands Regional Climate Assessment. Washington, D.C.: Island Press. 199 pp.

Kumar, C. P. 2012. *Assessing the Impact of Climate Change on Groundwater Resources*. India Water Week 2012 - Water, Energy and Food Security: Call for Solutions. 10–14 April 2012. New Delhi.

Manton, M.J. et al. 2001. Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1916-1998. *International Journal of Climatology*. 21. 269–284.

Mimura, N. 1999. Vulnerability of island countries in South Pacific to sea level rise and climate change. *Climate Research*. 12. 137–143.

Mitchell, W. et al. 2001. Sea level rise in Australia and the Pacific. In M. Grzechnik and J. Chittleborough, eds. *Proceedings of the Pacific Islands Conference on Climate Change, Climate Variability and Sea Level Rise*, Linking Science and Policy. Flinders Press, South Australia.

Ramussen, P. et al. 2013. Assessing impacts of climate change, sea level rise, and drainage canals on salt water intrusion to coastal aquifer. *Hydrology and Earth System Science*. 17. 421–443.

Rozell, D.J. and T. Wong. 2010. Effects of climate change on groundwater resources at Shelter Island, New York State, US. *Hydrogeology Journal*. 18. 1657–1665.

Salvat, B. 2002. Status of Southeast and Central Pacific reefs 'Polynesia Mana Node': The Cook Islands, French Polynesia, Kiribati, Niue, Tokelau, Tonga, Wallis and Futuna. In C. R. Wilkinson (ed). *Status of Coral reefs in the World 2002*. GCRMN Report, Australian Institute of Marine Science, Townsville.

Terry, J.P and T.F.M. Chui. 2012. Evaluating the fate of freshwater lenses on atoll islands after eustatic sea-level rise and cyclone-driven inundation: A modeling approach. *Global and Planetary Change*. 88–89. 76–84.

United Nations. 2013. *World Population Prospects: The 2012 Revision*. United Nations Department of Economic and Social Affairs, Population Division. CD-ROM Edition.

United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). 2006. *State of the Environment in Asia and the Pacific 2005: Economic Growth and Sustainability*. United Nations. Bangkok.

______. 2012. *Statistical Yearbook for Asia and the Pacific 2012*. United Nations, Bangkok.

World Bank. 2013. *PovcalNet: An Online Poverty Analysis Tool* (at http://iresearch.worldbank.org/PovcalNet/index.htm).

World Bank. World Development Indicators (WDI). http://data.worldbank.org/data-catalog/world-development-indicators (accessed 11 October 2013).

Chapter 3

FRAMEWORK AND METHODOLOGY

I. Study Framework and Modeling

The potential economic impacts of climate change can be quantitatively assessed by modeling a complex set of relationships that link projected changes in global average surface temperature with changes in GDP. For specific regional, national, and local impact assessments, the modeling must also take into account localized climate information and the existing regional and sectoral economic structures.

The study comprises the following three broad components (Figure 3.1).

Component 1 – Climate modeling. The first component presents a high-resolution simulation of future climate over the Pacific region by dynamically downscaling global climate data using a regional climate model to generate locally relevant climate information. This component mostly relies on the use of general circulation models (GCMs) and climate downscaling using a regional climate model (RCM). This component projects regional and local climatic parameters (such as temperature and rainfall) and analyzes climatic-related events (such as sea-level rise and the El Niño-Southern Oscillation [ENSO]) under projected climate change conditions.

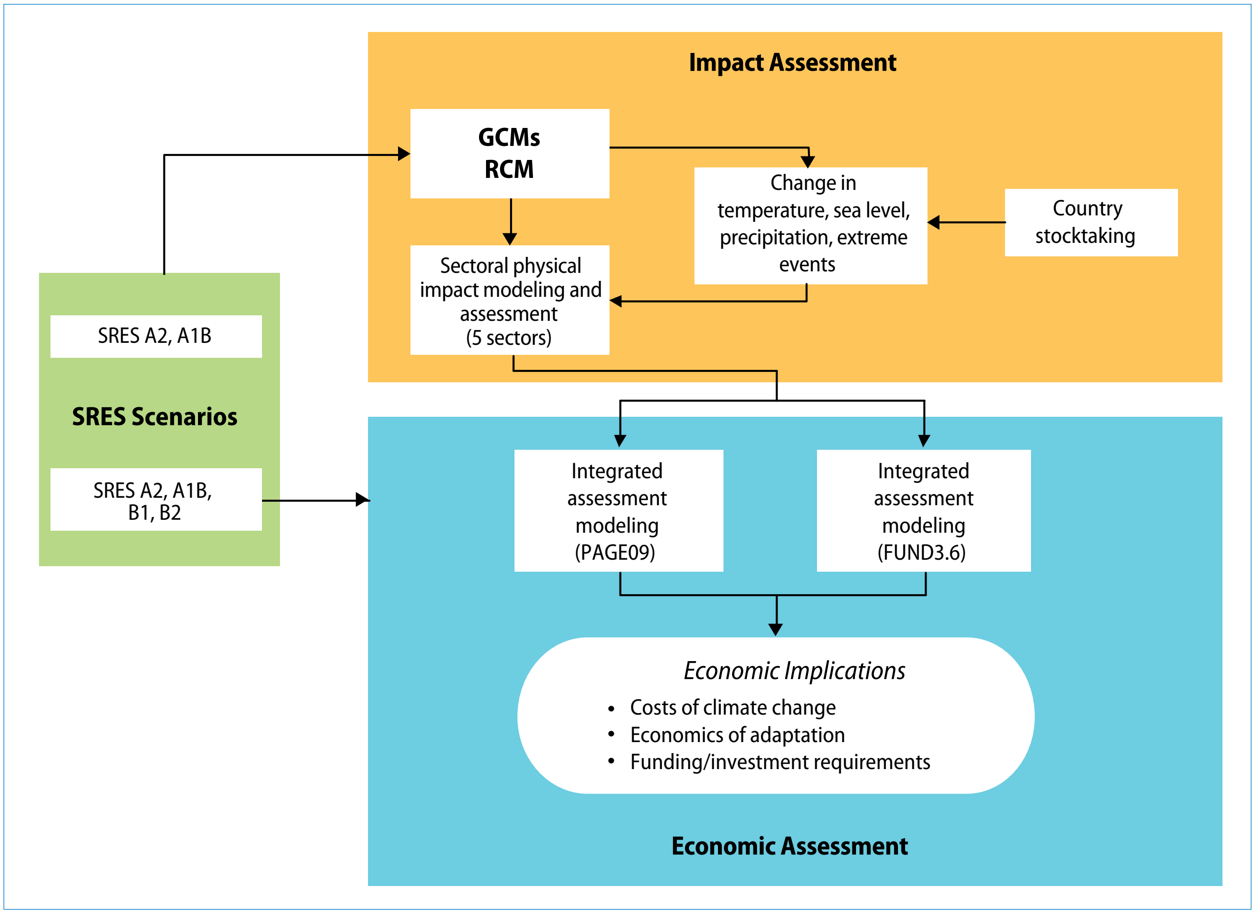
Component 2 – Sector impact assessment. The second component quantifies the potential impacts of climate change on selected key sectors in the Pacific such as agriculture, fisheries, tourism, coral reefs, and human health. A set of sector models are employed to augment the current literature with specific sector details, while some estimates from these models are then used for a better understanding of the possible economic impacts of climate change in the Pacific.

Component 3 – Economic impact assessment. The third component employs an economic modeling framework that integrates a set of climate projections and physical impacts to provide estimates of the potential economic impact of climate change for the Pacific. This component relies mainly on the use of two integrated assessment models.

The study provides an economic assessment of the potential impacts of climate change for all 14 Pacific DMCs. Since the available data allows for more detailed climate and sector analyses for Fiji, PNG, Samoa, Solomon Islands, Timor-Leste, and Vanuatu, local climate and national impact results are presented for these countries.

To validate climate change projections derived from the modeling for each country, stocktaking was done through a review of the literature on climate change vulnerability concerns and responses, including observations on historical and current climate patterns. Responses taken by governments were also reviewed, particularly their respective National Adaptation Programme of Action (NAPA), communications to the IPCC, and initiatives by nongovernment and multilateral agencies. Ongoing

Figure 3.1: Modeling Framework



GCM = general circulation model, RCM = regional climate model, SRES = Special Report on Emissions Scenarios.

coping and adaptation measures, including constraints to building adaptive capacity, were also reviewed. The stocktaking phase of the study provided additional information for establishing baseline conditions for the sector-impact modeling.

Section II below provides more information and details on the methodological approach. Section III discusses known caveats and limitations of studies of this nature. These need to be taken into account when formulating investment options and policy recommendations.

II. Methodology and Key Assumptions

Various climate models, physical-impact models, and economic models have been used to simulate the potential impacts of climate change in the Pacific region. These are briefly discussed below.

A. Emissions Scenarios[5]

The IPCC published its *Special Report on Emissions Scenarios* (SRES) in 2000 describing a set of emissions scenarios that have been used for projections of possible future climate change (IPCC 2000). These were used in the IPCC Third Assessment Report (TAR) published in 2001 and the IPCC AR4 published in 2007. The SRES scenarios were designed to explore future developments in the global environment

[5] Since the finalization of this study, the IPCC has issued its Fifth Assessment Report (AR5). A new set of scenarios, known as Representative Concentration Pathways (RCP), was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. As noted in the report of Working Group 1 (IPCC 2013), projected climate change based on RCP is similar to AR4 in both patterns and magnitude after accounting for scenario differences. Furthermore, projections of sea-level rise are larger than in IPCC AR4 primarily because of improved modeling of land-ice contributions. Hence, while the climate modeling approach available in AR5 differs from the approach thus far available, climate change projections are of a similar nature and do not run counter to the modeling results presented in this study.

with special reference to the production of greenhouse and aerosol emissions. These scenarios are components of various "storylines" which allow for a large range of projections of future emissions of greenhouse gases (Box 3.1). It is important to note that the IPCC did not specify which of these scenarios may be deemed more likely to occur. As such, none of the SRES scenarios represents a "best guess" of future emissions.

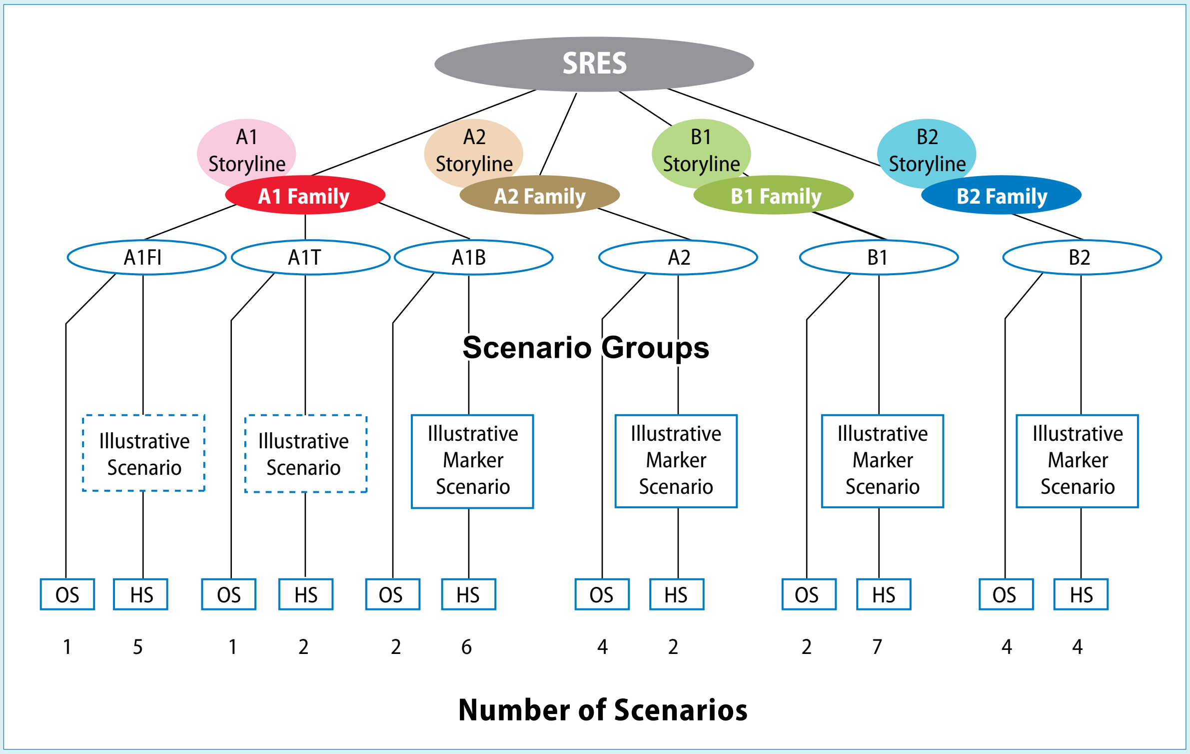
Box 3.1: Emissions Scenarios of the IPCC Special Report on Emissions Scenarios (SRES)

The A1 storyline and scenario family describes a future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1 scenario family can be categorized into three groups depending on their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

The A2 storyline and scenario family assumes a very heterogeneous world. Global population further increases with fertility patterns converging only slowly across regions. Economic development is driven primarily at the regional level and per capita income growth and technological advances are relatively more fragmented.

The B1 storyline and scenario family describes a convergent world. Global population peaks in mid-century and declines thereafter similar to the A1 storyline. Economic structures change rapidly toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 storyline and scenario family depicts a world where local solutions to economic, social, and environmental sustainability are emphasized. Global population increases continuously, but at a rate lower than A2. The levels of economic development are intermediate, with less rapid and more diverse technological change than in the B1 and A1 storylines. The scenario is also focused on local and regional levels of environmental protection and social equity.
Altogether, about 40 SRES scenarios have been developed with no assigned probabilities of occurrence. The set of scenarios consist of six groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel)



Source: IPCC 2000.

B. Component 1: Climate Modeling

Downscaling is conducted to provide higher-resolution climate change data for the Pacific DMCs. The regional model is driven by ECHAM-5 GCM, which was developed at the Max Planck Institute for Meteorology. Dynamic downscaling of 20x20 km horizontal-grid resolution of climate change data was done for each of the Pacific DMCs, except for PNG where grid resolution was set at 30x30 km due to its much larger land area.

The study adopts both GCMs and RCM for climate modeling and downscaling as well as for the analysis of ENSO and extreme weather events. The climate modeling component aims to (i) construct future climate parameters for the region, (ii) investigate changes in interannual rainfall variability impacted by ENSO under current and future climate conditions, and (iii) provide a basis for the physical and economic assessment of climate change. The modeling is conducted under two IPCC emissions scenarios (A1B and A2) for two time periods of 2041–2060 (2050 mean) and 2061–2080 (2070 mean) at the 0.1°x0.1° horizontal-grid resolution.

Providing two future scenarios over two time periods allows for ranges of climate change impacts in terms of scenarios and time periods. Changes in different climatic parameters (such as temperature and rainfall) and other climatic related events (such as sea-level rise and ENSO) under climate change conditions were determined in relation to a baseline climatic condition (1981–2000).

The list of GCMs used in this study is provided in Table 3.1. The RCM used is the Regional Climate Model Version 3 (RegCM3).[6] The modeling is based on datasets developed from observations as well as from GCMs outputs. The observed rainfall data used as reference in this study is taken from the gridded CRU TS2.1 dataset of the Climate Research Unit (CRU). This data was chosen due to its long-term record and as substitute for the unavailability of rain-gauge stations data from each country. The CRU data, reconstructed from monthly climate observations obtained from meteorological stations, comprises

Table 3.1: List of GCMs Used in the Analysis

No	Model name	Institution	Ocean resolutions	References
1	bccr_cm20	BCCR (PRC)	-	-
2*	cccma_cgcm31_t47	CCCMA (Canada)	1.85°x1.85° L29	Kim et al. 2002
3*	cccma_cgcm31_t63	CCCMA (Canada)	-	-
4	cnrm_cm3	Meteo-France/CNRM (France)	2°x0.5° L31	Salas-Mélia 2002
5	csiro_mk3.0	CSIRO (Australia)	1.875°x0.84° L31	Gordon et al. 2002
6	csiro_mk3.5	CSIRO (Australia)	1.875°x0.84° L31	Collier et al. 2007
7	gfdl_cm2.0	GFDL (US)	1°x1/3° L50	Delworth et al. 2006
8	gfdl_cm2.1	GFDL (US)	1°x1/3° L50	Delworth et al. 2006
9*	giss_aom	NASA/GISS (US)	4°x3° L16	Lucarini and Russell 2002
10*	giss_model_er	NASA/GISS (US)	2°x2° L16	Schmidt et al. 2005
11	iap_fgoals_10g	LASG/IAP (PRC)	1°x1° L33	Yu et al. 2004
12	inmcm3.0	INM (Russia)	2.5°x2° L33	Volodin and Diansky 2004
13	miroc32_hires	CCSR/NIES/FRCGC (Japan)	0.28°x0.1875° L47	K-1 model developers 2004
14*	miub_echo_g	MIUB (Germany), IKMA (Republic of Korea)	0.5° L20	Legutke and Voss 1999
15*	mpi_echam5	MPI-M (Germany)	1.5°x1.5° L40	Jungclaus et al. 2006
16*	mri_cgcm232a	MRI (Japan)	2.5°x0.5° L23	Yukimoto and Noda 2002
17	ncar_ccsm3.0	NCAR (US)	1.125°x0.27° L40	Collins et al. 2006
18	ncar_pcm1	NCAR (US)	2/3°x1/2° L32	Washington et al. 2000
19	ukmo_hadcm3	Hadley Centre (UK)	1.25° L20	Gordon et al. 2000
20	ukmo_hadgem1	Hadley Centre (UK)	1°x1/3° L40	Johns et al. 2004

Note: * denotes GCMs that are used for climate projection and downscaling.

[6] http://users.ictp.it/RegCNET/model.html

rainfall data and other climate variables (Mitchell and Jones 2005). The grid data covers global land area with 0.5°x0.5° horizontal-grid resolution for the period of 1901–2002.

To analyze ENSO and its impact on rainfall under current and future climate, the study uses reconstructed sea surface temperature (SST) observation data from HadISST1.1 (Rayner et al. 2003) and from the output of 20 GCMs. The HadISST 1.1 data were reproduced as a substitute for the global sea-ice and sea-surface temperature (GISST) dataset, and make a better representation of regional SST than GISST. From the GCMs, the SST data were derived from ocean component under the 20th Century Climate in Coupled Models (20C3M) for the historical SST, and under A1B and A2 emissions scenarios for future projections.

The rainfall climatology of each country was calculated separately from the gridded CRU dataset for the period of 1971–2002. For the analysis of ENSO, SST anomalies were investigated in the well-known Niño regions.[7] The indices are monthly SST anomalies calculated by removing seasonal cycles (monthly climatology) and trends. The impacts of ENSO on current and future rainfall were estimated using pattern correlation and coefficient regressions during different periods. In addition, this study also performs analyses of the spatial-temporal patterns of ENSO based on the result of empirical orthogonal function (EOF) analysis.

For long historical rainfall and temperature data, RegCM3 is run under initial boundary condition data from ECHAM5-GCM and GISST sea surface temperature data (Rayner et al. 2003) covering the period September 1957 to July 2002, excluding the data in year 1961 and 1982 because of erroneous ERA-40 data. The results from RegCM3 were validated using observed data from the gridded CRU TS2.1 dataset. To project future conditions under the two emissions scenarios, seven GCMs (indicated with an * in Table 3.1) are downscaled to high resolution (0.1°x 0.1°) with the assistance of outputs from RegCM3 runs.

The potential impacts of climate change and sea-level rise can be gauged by both changes in coastal-flooding probabilities and changes in maximum wave height. Sea-level rise will have various physical and ecological effects on coastal systems and infrastructure. These include inundation, increased flood and storm damage, loss of wetlands, erosion, saltwater intrusion, and rising water tables. In particular, inundation analysis uses the ASTER Global Digital Elevation Model, taking into account trends from satellite altimetry, future sea levels from GCMs, and high tide patterns.

C. Component 2: Sector Impact Assessment

Detailed impact assessments have been estimated for agriculture, fisheries, coral reefs, tourism, and human health, using a set of sector models building on the available research in these areas. Brief details are presented below.

Agriculture

This component uses dynamic crop simulation model DSSAT (Decision Support System for Agro-technology Transfer) (Figure 3.2). The soil data are taken from world soil database[8], while climate data input are from CRU (historical data) and RegCM3 (future data). The analysis assesses the optimal planting times with and without irrigation (rainfed system), and also estimates the impact on yields of climate change and extreme climate events on yields. Only dominant crops are modeled and analyzed.

Fisheries

The effects of climate change on the Pacific's fisheries sector are expected to be significant. Channels for the climate change impact on the fisheries are complex, ranging from changes in sea temperature, wave patterns, and coral reef ecosystems to quality of water. No single model will be sufficient and the analysis will draw largely on findings of recent research.

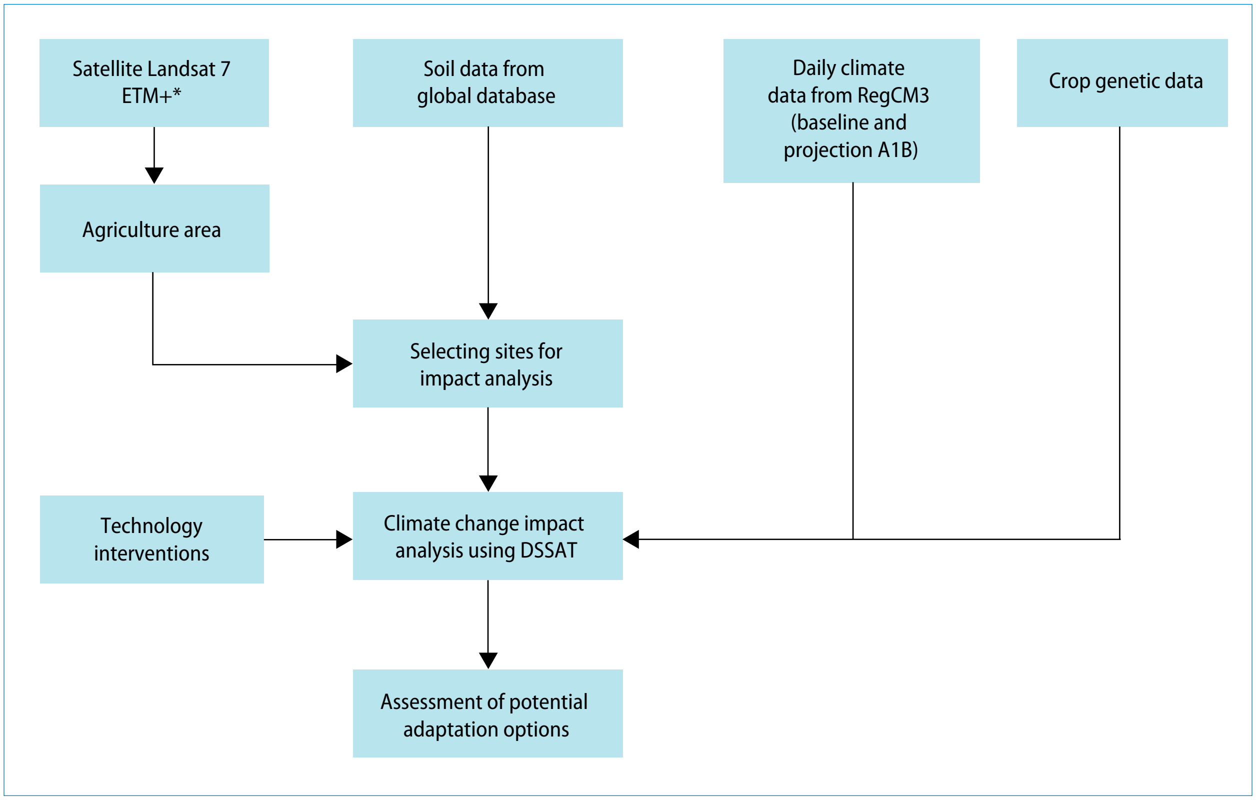
Tourism

Tourism, especially those in coastal areas, is one of the most important sectors in many Pacific DMCs.

[7] These being: Niño 1.2 (90°W-80°W, 10°S-0), Niño 3 (150°W-90°W, 5°S-5°N), Niño 3.4 (170°W-120°W, 5°S-5°N), and Niño 4 (160°E-150°W, 5°S-5°N).

[8] http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/html/

Figure 3.2: Dynamic Crop Simulation Model



*Note: The ETM+ is a multispectral scanning radiometer capable of providing high-resolution imaging information of the Earth's surface.

International tourism is likely to suffer from climate change as tourists tend to prefer an ideal climate for their holiday destinations.

The Hamburg Tourism Model (HTM) describes, at a high level of geographic disaggregation, changes in tourist behavior as a result of climate change. At the core of the model is a matrix that identifies tourism flows from one country to another. This matrix is perturbed by different scenarios of population, by changes in per capita income, and by climate change. The model also computes changes in the average length of stay and expenditures by tourists.

Coral Reefs

A new model was developed to evaluate the impact of climate change on coral reefs. The model focuses on coral bleaching caused by thermal stress, which is believed to be one of the main causes of the deterioration of coral reefs.

The model evaluates the coral cover in a stochastic or random manner using Monte Carlo analysis with 250 runs. The probability of a bleaching event is set at the level (6.5%) that allows for the expected cover to be 80% of the maximum cover under the current climate (Harrell Yee and Barron 2010). The model simulates that the probability of bleaching rises linearly to 12.5% by 2050 (Burke et al. 2011).

Human Health

The impact assessment of climate change on human health considers the mortality and morbidity trends resulting from global mean temperature rises particularly with respect to respiratory diseases caused by thermal (heat and cold) stress and vector-borne diseases such as malaria and dengue fever.

The model used to estimate the climate change impact on human health is based on Tol (2002a, 2002b). The model uses data on temperature and precipitation and takes into account the availability of health-care services and the ability of the population to purchase medicine. Heat and cold stress is assumed to have an effect only on the elderly and among the urban population. The share of people over 65 years of age is calibrated to data in the World Resources Databases[9] and is driven by per capita income. The share of the urban population from among the total population is also based on the World Resources Databases. In terms of thermal stress-related health disorders, the quality of housing and the availability of air conditioning are also considered.

D. Component 3: Economic Assessment

A large number of integrated impact assessment models (IAMs) have been developed and are widely used to model the complex linkages as well as the interactions and feedback between the economy and the climate system. These models are motivated by the need to balance the dynamics of carbon accumulation in the atmosphere and by the dynamics of de-carbonization of the economy (Nordhaus 1994). IAMs are widely used to provide

Box 3.2: The FUND3.6 Model

The FUND model was originally set up to study the role of international capital transfers in climate policy. However, it evolved into a model capable of studying impacts of climate change in a dynamic context. It is now often used to (i) perform cost-benefit and cost-effectiveness analyses of greenhouse-gas emissions reduction policies; (ii) study equity of climate change and climate policy; and (iii) support game-theoretic investigations of international environmental agreements.

Three features of the FUND model make it uniquely suited to investigate the relationship between economic development and climate impacts.

First, it has regionally disaggregated estimates of the impacts of climate change. This allows explicit accounting for the different levels of development experienced by the different regions of the world. Second, climate impacts in FUND are specified separately for different kinds of impacts that effect human welfare. As such, structural differences between regions in the vulnerability to climate change impacts are accounted for.

The application of FUND in this study was based on the following underlying assumptions:

Exogenous assumptions. They were made with respect to rates of population growth, economic growth, autonomous energy-efficiency improvements, the atmospheric concentration of carbon dioxide, global and national mean surface-air temperature, and sea-level rise.

Climate impact module. This included the following categories: agriculture; forestry; sea-level rise; cardiovascular and respiratory disorders related to heat stress, malaria, dengue fever, schistosomiasis, and diarrhea (Link and Tol 2004); energy consumption; water resources; unmanaged ecosystems (Tol 2002a, 2002b); and tropical and extra tropical storms (Narita et al. 2009, 2010).

Climate change related damages. These were attributed to either the rate of change (benchmarked at 0.04°C per year) or the level of change (benchmarked at 1.0°C).

Vulnerability to climate change. This accounted for changes in population growth and economic growth and in technological progress. Some systems are expected to become more vulnerable over time with increasing climate change, such as water resources (with population growth), heat-related disorders (with urbanization), and ecosystems (with higher per capita income). Projected to become less vulnerable at least over the long term (Tol 2002b) are other systems such as energy consumption (with technological progress), agriculture (with economic growth), and vector-and water-borne diseases (with improved health care). Income elasticities (Tol 2002b) are estimated from cross-sectional data or are taken from the literature. Heat and cold stress is assumed to have an effect only on the elderly. Heat stress is assumed to affect only the urban population.

Climate change impacts. The impacts on agriculture, forestry, energy, water, storm damage, and ecosystems are directly expressed in monetary values without an intermediate layer of impacts measured in their "natural" units (Tol 2002a). Impacts of climate change on energy consumption, agriculture, and cardiovascular and respiratory diseases explicitly recognize that there is a climatic optimum that is determined by a variety of factors, among them plant physiology and the behavior of farmers. Impacts can either be positive or negative depending on whether the actual climate conditions are moving toward or away from the climatic optimum. Impacts are larger if the initial climate conditions are farther away from the optimum climate. The impacts of not being fully adapted to new climate conditions are always negative (Tol 2002b). The impacts of climate change on coastal zones, forestry, tropical and extratropical storms, unmanaged ecosystems, water resources, diarrhea, malaria, dengue fever, and schistosomiasis are modeled as simple power functions.

Source: Tol (2011) and http://www.fund-model.org/home (accessed in 08 October 2013).

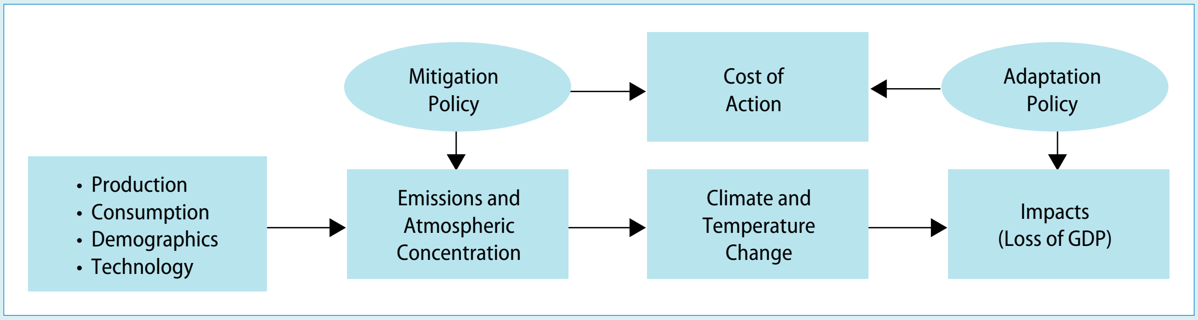
9 http://earthtrends.wri.org.

Box 3.3: The PAGE09 Model

PAGE09 is a new IAM that provides an economic value for the impacts of climate change and for the costs of policies to abate and to adapt to it. The model is designed to inform policymakers of the costs and benefits of climate action and inaction.

PAGE09 is the improved version of PAGE2002, which was used to estimate the impacts and calculate the social cost of CO_2 emissions in the Stern Review (Stern, 2007) and in ADB's review of climate change in Southeast Asia (ADB, 2009). PAGE09 takes into account the latest scientific and economic information available primarily in IPCC (2007). Calculations are made for eight world regions and ten time periods until year 2100.

Chain of impact and policy analysis in the PAGE09 model



PAGE09 has updated various parameters of PAGE2002 in terms of science, impacts, abatement costs, and adaptation as specified below:

Science:

Inclusion of all six gases included in the Kyoto protocol;
Inclusion of transient climate response;
Modification of the feedback from temperature to CO2 concentration;
Land temperature patterns by latitude;
Explicit incorporation of sea-level rise.

Impacts:

Impacts as a proportion of GDP;
Discontinuity impacts;
Equity weighing of impacts.

Abatement costs:

In PAGE09, marginal abatement cost (MAC) for each gas in each region is represented by a continuous curve, with an optional possibility of negative costs for small cutbacks. The curve is specified by three points and by two parameters describing the curvature of the MAC curve below and above zero cost, respectively.

Adaptation:

Adaptation policy in PAGE09 includes 7 inputs for 3 sectors (sea level, economic, and non-economic) for 8 regions, giving 168 inputs in all. This is a simplification compared to the 480 inputs in PAGE2002.

The adaptation costs are specified as a percentage of GDP per unit of adaptation. Adaptation costs are assumed to benefit from autonomous technological change.

Abatement and adaptation costs can be fully equity-weighted, partially equity-weighted or not equity-weighted. The latter options allow users to evaluate policies in which the adaptation and/or mitigation costs to poor countries are paid by transfers from rich countries.

Source: Hope (2011) and ADB (2009).

useful information and scientific insights for climate policy, and they are often used to estimate the economic impacts of climate change as well the costs and benefits of mitigation strategies considered for future climate policy.

The assessment of the potential economic impacts of climate change in the Pacific uses two IAMs, namely (i) Version 3.6 of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND3.6), and (ii) and version 9 of the Policy Analysis of the Greenhouse Effect (PAGE09).

The FUND3.6 model aims to advise policymakers on the characteristics of an optimal policy rather than to evaluate the economic and climate consequences of proposed policies (Tol 1997). This model distinguishes 207 countries and runs from year 1995 to 2100 in time steps of five years. The model scenarios are defined by exogenous assumptions on the rates of population growth, economic growth, autonomous energy-efficiency improvements, the atmospheric concentration of carbon dioxide, global and national mean surface-air temperature, and sea-level rise (Box 3.2). The strength of this model is that it illustrates and provides estimates of climate impacts at sector levels. The climate module under FUND3.6 includes agriculture; forestry; sea-level rise; cardiovascular and respiratory disorders related to cold and heat stress; malaria; dengue fever; schistosomiasis; energy consumption; water resources, unmanaged ecosystems (Tol 2002a, 2002b); diarrhea (Link and Tol 2004); and tropical and extratropical storms (Narita et al. 2009, 2010).

PAGE09 is an IAM that values the impacts and costs of climate change for both mitigation and adaptation. It is designed to help policymakers understand the costs and benefits of action and inaction. The strength of this model is that it uses simple equations to simulate the results from more complex specialized scientific and economic models as well as illustrates the probabilistic range of outcomes and uncertainties associated with climate change (Box 3.3). The model distinguishes eight world regions and runs ten time-periods to the year 2100 for four impact sectors (sea level, economic, non-economic, and discontinuities).

The two models have their respective strengths and weaknesses. In addition to the overall climate impact for the Pacific at the regional level, each model has been applied to specific areas of its comparative advantage. FUND3.6, with details in impact sectors, is used to assess sources of future losses and to identify most vulnerable sectors at the national level for selected countries. PAGE09 has only regional grouping in its specification but being stochastic or random in nature, it can be used to analyze the economic implications of climate change and responses, taking into account uncertainties associated with climate process, physical impacts, and economic parameters as well as the possibility of catastrophic risk. To allow for comparison, both models are simulated out to the year 2100 based on a consistent set of scenarios and parameters.

To explicitly capture climate change and its implications in the Pacific DMCs, the two models have been calibrated to have the future climate condition consistent with what the regional climate model suggested for the Pacific DMCs.

The key outputs of the two IAMs are (i) economic cost of climate change (e.g., % GDP loss economy-wide and sector-specific), (ii) cost-benefit and effectiveness of adaptation options, and (iii) funding need (total adaptation cost and marginal adaptation cost).

III. Caveats and Limitations

When interpreting the findings of this study, caution should be exercised because of data limitation, the large scale of the study area, and uncertainties in climate change modeling (Box 3.4). As with any other simulation exercise, results are subject to model specification and assumptions underlying the models. Changes in assumptions or parameter values, or combinations of both, will lead to different results.

Regarding the climate modeling, the study covers the Pacific region but detailed impact assessments were done only for six Pacific DMCs. Given the coarse resolution nature of the GCMs, RegCM3 was used to downscale GCMs results so that they can represent future temperature trends and climate patterns over land areas of the Pacific. To ensure consistency, the Pacific blocks in FUND3.6 and PAGE09 were calibrated mainly in terms of temperature rise.

As to the physical-impact and sector-assessment modeling, the models use outputs on sea-level rise, coastal impact (land loss), and agricultural impact (yield loss) to the extent possible. However, in terms of their coverage, the climate and sector models employed in the study are by no means complete. Owing to their many limitations, they should not be used independently for understanding the true magnitude of climate change impacts on various aspects of physical and sector environments in the Pacific. Moreover, the analysis of the modeling exercise should be used only when necessary to complement the available research findings and literature to date.

On the economic-assessment modeling, although using two IAMs may not necessarily yield robust results considering the variance in the results, they provide a useful range within which climate change policies may be drawn. Since FUND3.6 and PAGE09 do not directly take the output of physical models as inputs, these two parameters were calibrated to make their projected physical impacts on these three aspects consistent with those suggested by the impact-assessment sector models. Estimates are also contingent upon how future scenarios unfold, how the time-horizon is envisaged, and how the societies value their futures and their future generations.[10]

Given the foregoing caveats, the results of this study should be interpreted only as indicative of the possible impacts of climate change, not as predictions or forecasts.

Box 3.4: Climate change Modeling Uncertainties

Estimating how climate change may evolve is subject to considerable uncertainty. Some of the well-recognized uncertainties are discussed below.

Climate Uncertainty

Emissions. They are a function of projected population growth, technological innovation, and patterns of production and consumption, all of which influence the level of production and its degree of carbon intensity. As emissions reflect a confluence of many socioeconomic factors, they are difficult to accurately predict over a long time-horizon.

Atmospheric concentration and carbon sinks. Mapping greenhouse gas emissions into atmospheric concentration is subject to a high degree of uncertainty. The role and contribution of carbon sinks in extracting and releasing carbon from and to the atmosphere is a process that is not completely understood because it is subject to a number of complex feedback mechanisms.

Solar radiation and the effect of other gases. Climate is affected by other gases such as anthropogenic and natural aerosols (volcanic, for example) as well as by changing intensity of solar radiation. Uncertainty about their effect on temperature contributes to further uncertainty about future warming.

Climate sensitivity. The overarching parameter that drives all climate models is the temperature change that results from physical "climate forcing" (the greenhouse-gas effect) owing to increased concentration of greenhouse gases. For this reason, climate sensitivity—the relationship between temperature and greenhouse concentration—is generally considered to be the greatest source of uncertainty in climate modeling.

Model Uncertainty

Model specification. In a model with a limited number of equations, it is not possible to capture all known factors that drive changes in climate conditions and human activities. Among the sources of difficulties are uncertainty pertaining to the functional form of key equations, the specification of key parameters, data inputs, the scale and resolution, and the nature and interpretation of the empirical estimation properties. Each model is constrained by the nature of its intended focus, and different models inevitably lead to differences in results.

Damage function. At the global level, total climate change damage is often simplified as a direct function of temperature change, and the parameter behind this is subject to uncertainty. This modeling simplification, being intended to capture a vast array of impacts, cannot adequately reflect the detailed nature of the climate problem.

Source: ADB (2009).

[10] Pindyck (2013) and Stern (2013) discuss in greater detail the limitations of integrated impact-assessment models.

References

Asian Development Bank (ADB). 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review*. Manila.

Burke, L. et al. 2011. *Reefs at Risk*. Washington, D.C. World Resources Institute.

Collier, M. A. et al. 2007. CSIRO Mk3 *Climate System Model and Meeting the Strict IPCC AR4 Data Requirements*. MODSIM07 International Congress on Modelling and Simulation: Land, water & environmental management: integrated systems for sustainability. Modelling and Simulation Society of Australia and New Zealand. pp. 582–588.

Collins, W.D. et al. 2006. The community climate system model version 3 (CCSM3). *Journal of Climate*. 19. 2122–2143.

Delworth, T.L. et al. 2006. GFDL's CM2 global coupled climate models. Part I: Formulation and simulation characteristics. *Journal of Climate*. 19. 643–674.

Gordon, C. et al. 2000. The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics*. 16. 147–168.

Gordon, H.B. et al. 2002. *The CSIRO Mk3 Climate System Model*. CSIRO Atmospheric Research. CSIRO Atmospheric Research Technical Paper no. 60). 130 pp.

Harrell Yee, S. and M.G. Barron. 2010. Predicting coral bleaching in response to environmental stressors using 8 years of global-scale data. *Environmental Monitoring and Assessment*. 161. 423–438.

Hope, C. 2011. *The PAGE09 Integrated Assessment Model: A Technical Description*. University of Cambridge, Judge Business School. Cambridge.

Intergovernmental Panel on Climate Change (IPCC). 2000. *Special Report on Emissions Scenarios*. A Special Report.

______. 2007. *Climate Change 2007. The Physical Science Basis. Summary for Policymakers*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Secretariat. Switzerland.

______. 2013. Climate Change 2013. *The Physical Science Basis. Summary for Policymakers. Contribution of* Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Secretariat Switzerland.

Johns, T., et al. 2004. *HadGEM1 Model Description and Analysis of Preliminary Experiments for the IPCC Fourth Assessment Report*. U.K. Met Office. Exeter, U.K.

Jungclaus, J. H., et al. 2006. Ocean circulation and tropical variability in the coupled model ECHAM5/MPI-OM. *Journal of Climate*. 19. 3952–3972.

K-1 Model Developers. 2004. *K-1 Coupled Model GCM (MIROC) Description*. H. Hasumi and S. Emori (eds.), Center for Climate System Research, University of Tokyo, 34pp.

Kim, S.J. et al. 2002. A coupled climate model simulation of the Last Glacial Maximum, Part 1: transient multi-decadal response. *Climate Dynamics*. 19. 515–537.

Legutke, S. and R. Voss. 1999. *The Hamburg Atmosphere-Ocean Coupled Circulation Model ECHO-G*. Technical Report No. 18, German Climate Computer Center (DKRZ).

Link, P.M. and R.S.J. Tol. 2004. Possible economic impacts of a shutdown of the thermohaline circulation: an application of FUND. *Portuguese Economic Journal*. 3. 99–114.

Lucarini, V. and G. L. Russell, 2002. Comparison of mean climate trends in the Northern Hemisphere between National Centers for Environmental Prediction and two atmosphere-ocean model forced runs. *Journal of Geophysical Research*. 107. D15,

Mitchell, T.D. and P.D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology*. 25. 693–712.

Narita, D., Anthoff, D. and R.S.J.Tol. 2009. Damage costs of climate change through intensification of tropical cyclone activities: an application of FUND. *Climate Research*. 39. 87–97.

______. 2010. Economic costs of extratropical storms under climate change: an application of FUND. *Journal of Environmental Planning and Management*. 53. 371–384.

Nordhaus, W.D. 1994. *Managing the Global Commons: The Economics of Climate Change*. Massachusetts Institute of Technology. MIT Press.

Pindyck, R. 2013. *Climate Change Policy: What do Models Tell US*?. National Bureau of Economic Research. Working Paper 19244.

Rayner, N.A. et al. 2003. Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *Journal of Geophysical Research*. 108 4407, doi:10.1029/2002JD002670, D14.

Salas-Melia, D. 2002. A global coupled sea ice-ocean model. *Ocean Modelling*. 4. 137–172.

Schmidt, G.A. et al. 2005. Modelling atmospheric stable water isotopes and the potential for constraining cloud processes and stratosphere-troposphere water exchange. *Journal of Geophysical Research*.110. D21314.

Stern, N. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge and New York: Cambridge University Press.

______2013. The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models. *Journal of Economic Literature*. 51. 3. 838–859.

Tol, R.S.J. 1997. On the optimal control of carbon dioxide emissions: An application of FUND. *Environmental Modeling & Assessment*. 2. 151–163.

______. 2002a. Estimates of the damage costs of climate change - Part 1: Benchmark estimates. *Environmental and Resource Economics*. 21. 47–73.

______. 2002b. Estimates of the damage costs of climate change - Part II: Dynamic estimates. *Environmental and Resource Economics*. 21. 135–160.

______. 2011. *The Economic Impact of Climate Change on Pacific Island Nations*. Draft report submitted to the Asian Development Bank.

Volodin, E. M. and N. A. Diansky. 2004. El-Niño reproduction in coupled general circulation model of atmosphere and ocean. *Russian Meteorology and Hydrology*. 12. 5–14.

Washington, W.M. et al. 2000. Parallel climate model (PCM) control and transient simulations. *Climate Dynamics*. 16. 755–774.

Yu, Y., X. Zhang, and Y. Guo. 2004. Global coupled ocean-atmosphere general circulation models in LASG/IAP. *Advanced Atmospheric Science*. 21. 444–455.

Yukimoto, S. and A. Noda. 2002. *Improvements of the Meteorological Research Institute Global Ocean-atmosphere Coupled GCM(MRI-CGCM2) and its Climate Sensitivity*. Meteorological Research Institute, Japan.

Chapter 4
CLIMATE SCENARIOS FOR THE PACIFIC

The effects of global climate change are multifaceted. Rising global surface temperature would continue to cause the oceans to warm up and expand and the glaciers and ice masses to melt. The resulting rise in sea level would erode coastal areas, make flooding more frequent, and disrupt the delicate balance between ocean dynamics and ecosystems. Changing climate could also profoundly alter the historical patterns of rainfall and climate variability as in the case of the ENSO, thus leading to more frequent and/or more intense extreme weather events such as floods, droughts, and storms. Most of these effects of climate change would have adverse economic and human consequences.

This chapter describes possible future changes and extremes of climate in the Pacific region. To project local climate conditions in the Pacific region, climate downscaling was conducted for Fiji, PNG, Samoa, Solomon Islands, Timor-Leste, and Vanuatu. A regional climate model (RegCM3) was set up for dynamic downscaling at 20x20 km horizontal grid resolution for all of these countries, except for PNG where grid resolution was set at 30x30 km due to its much larger land area. The regional model was based on ECHAM-5 GCM. The chapter then provides projections for the periods of 2041–2060 (2050 mean) and 2061–2080 (2070 mean) under A1B (medium) and A2 (high) greenhouse and aerosol emissions scenarios.

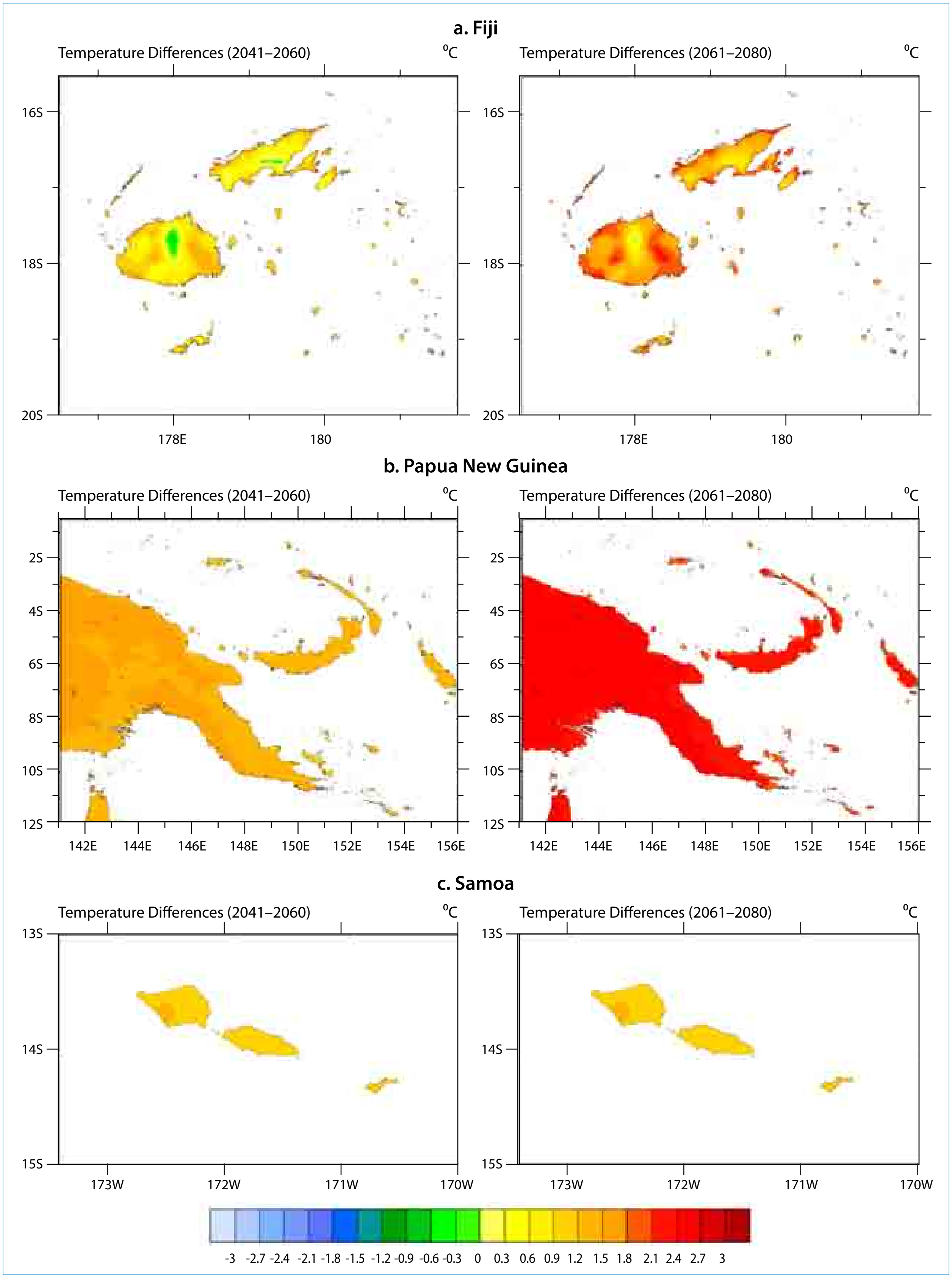
At the outset, it must be acknowledged that there remain considerable uncertainties regarding climate change. This is because the future level of global greenhouse-gas emissions is uncertain, and the available knowledge about the climate-earth-ocean system is inadequate for reliably forecasting local climate. The climate information and projections provided in this study should therefore be considered only as indicative, not predictive.

I. Temperature

Annual mean temperature is projected to rise in the Pacific relative to that of the 1981–2000 period (1990 baseline level). The downscaling results show that the annual mean temperature would increase for all countries in the region, with the 2070 levels consistently higher than the 2050 levels (Figure 4.1). There are variations in the annual mean temperature between and within the six countries studied. Most countries, or particular areas within countries, would experience up to a 1.8°C rise by 2050 under A1B scenario relative to the 1990 level. Given the observed increase in global mean temperature of approximately 0.5°C over the period 1981–2000 relative to the pre-industrial era, warming is projected to exceed 2.3°C by 2050 relative to the pre-industrial era.

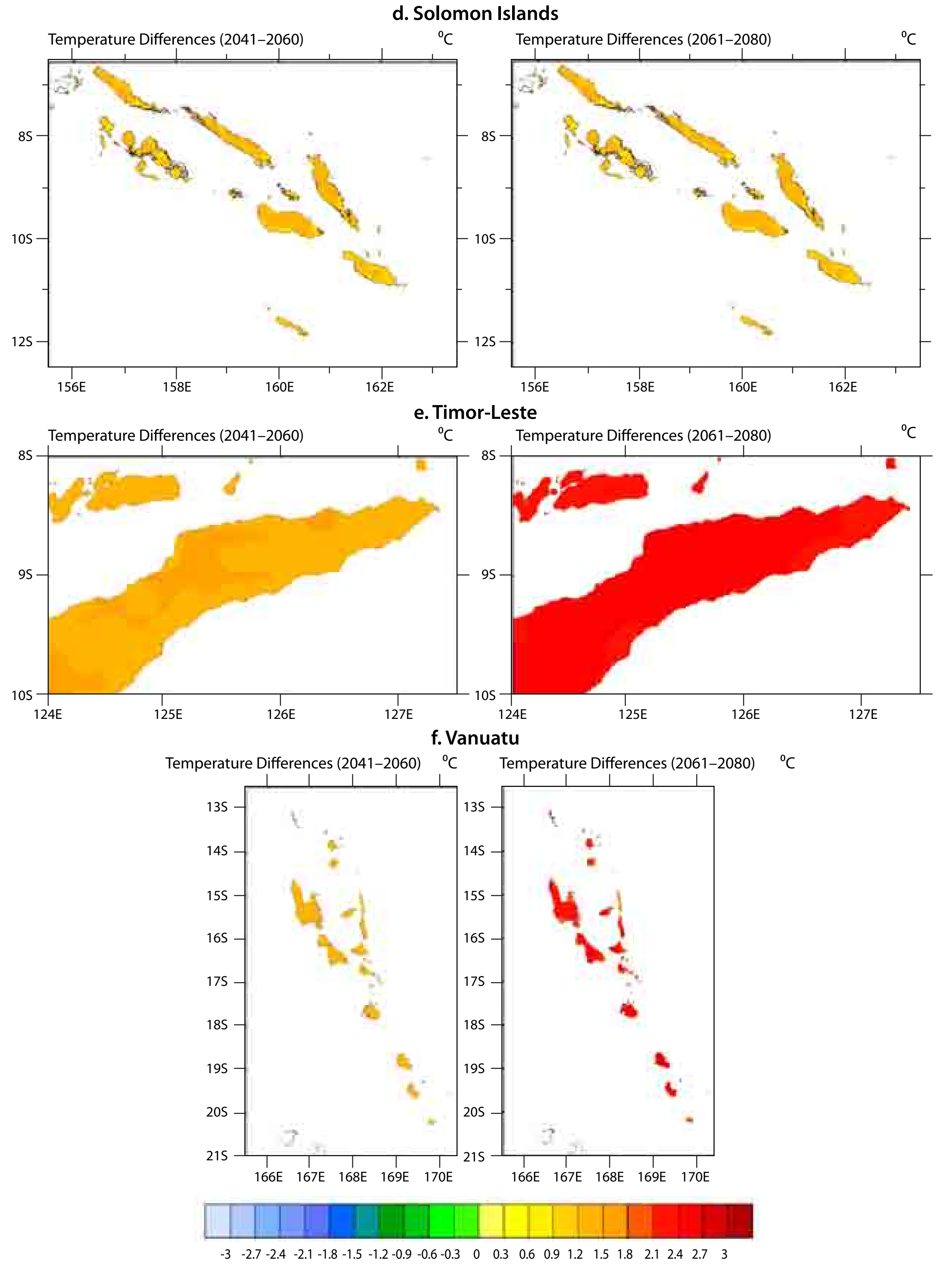
By 2070, Fiji and Samoa are projected to experience a temperature rise of approximately 2°C on average from the 1990 level (i.e., more than a 2.5°C rise on average from the pre-industrial level). PNG, Solomon Islands, Timor-Leste, and Vanuatu are expected to experience a temperature increase of more than 2.5°C on average by 2070, with some

Figure 4.1: Temperature Change under A1B Scenario: Fiji, PNG and Samoa



Source: ADB study team.

Figure 4.2: Temperature Change under A1B Scenario: Solomon, Timor-Leste, Vanuatu



Source: ADB study team.

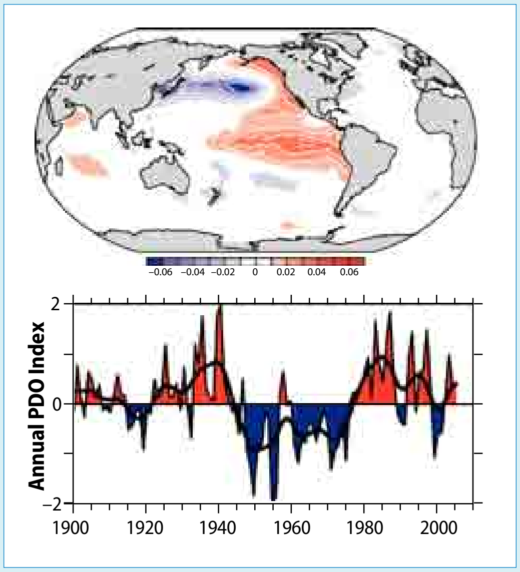
Box 4.1: El Niño-Southern Oscillation

ENSO events are a coupled ocean-atmosphere phenomenon. El Niño involves the warming of tropical Pacific surface waters from near the International Date Line to the west coast of South America, thus weakening the usually strong SST gradient across the equatorial Pacific, with associated changes in ocean circulation. The Southern Oscillation, the closely linked atmospheric counterpart of El Niño, involves changes in trade winds, tropical circulation, and precipitation. Historically, El Niño events occur about every 3 to 7 years, alternating with the opposite phases of below-average temperatures in the eastern tropical Pacific (La Niña). Changes in the trade winds, atmospheric circulation, precipitation, and associated atmospheric heating bring about extratropical responses. In the mid-altitudes, wavelike extratropical teleconnections are accompanied by changes in the jet streams and storm tracks.

ENSO has global impacts that are manifested most strongly in the northern winter months (November–March). Anomalies in mean sea-level pressure are much greater in the extratropics. The tropics feature large precipitation variations.

The nature of ENSO has varied considerably over time. Strong ENSO events occurred from the late 19th century through the first 25 years of the 20th century, and again after about 1950; there were few events of note from 1925 to 1950, with the exception of the major 1939–1941 event. The 1976–1977 climate shift (see figure below) was associated with marked changes in El Niño evolution, a shift to generally above-normal SSTs in the eastern and central equatorial Pacific, and a tendency towards more prolonged and stronger El Niños. Since IPCC TAR, considerable study has been done on the decadal and longer-term variability of ENSO and Pacific climate. Such decadal atmospheric and oceanic variations are more pronounced in the North Pacific and across North America than in the tropics; they are also present in the South Pacific, however, and evidence suggests they are at least in part forced from the tropics.

ENSO events involve large exchanges of heat between the ocean and atmosphere, thus affecting global mean temperatures. The 1997–1998 event was the largest on record in terms of SST anomalies, and the global mean temperature in 1998 was the highest on record (at least until 2005). Owing to the El Niño, the global mean surface-air temperatures were estimated to be 0.17°C higher for the year centered on March 1998. Extremes of the hydrological cycle such as floods and droughts are common with ENSO, and they are apt to be enhanced with global warming. For example, the modest 2002–2003 El Niño was associated with a drought in Australia, which was made much worse by record-breaking heat. Thus, whether observed changes in ENSO behavior are physically linked to global climate changes is a research question of great importance.



PDO: Pacific decadal oscillation.
Notes: The top portion shows the SST based on the leaping EOF SST pattern for the Pacific basin north of 20°N for 1901 to 2004 and projected for the global ocean (units are nondimensional). The bottom section shows annual time series. The smooth black curve shows decadal variations.

Source: IPCC 2007.

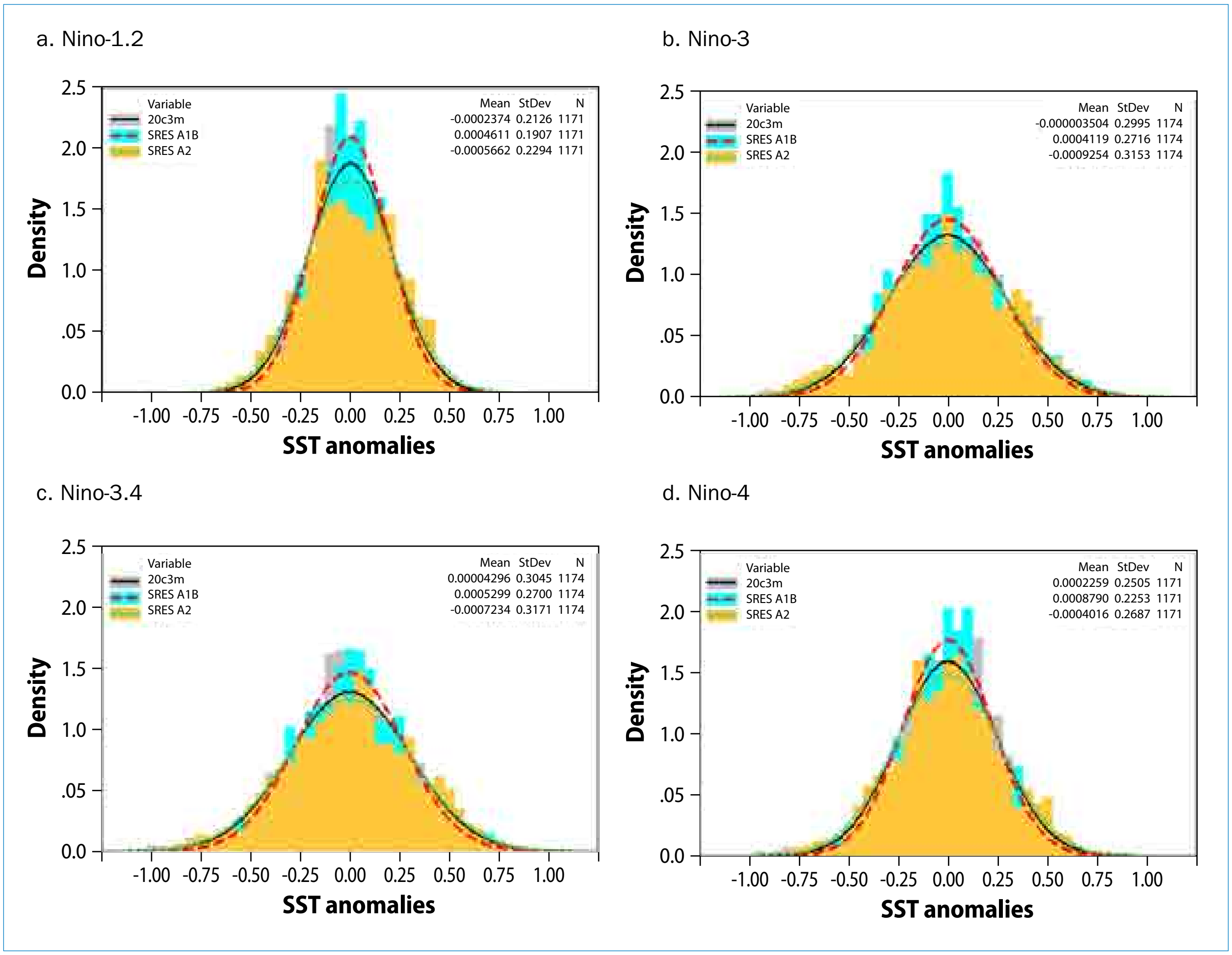
areas in these countries experiencing an increase of nearly 3°C in the same period relative to the 1990 level (Figure 4.2). Under higher emissions scenarios like the A1FI scenario, temperature increases would be even more pronounced.[11]

[11] It should be noted here that consistent with the IPCC AR4, the downscaling undertaken for this study indicates higher levels of temperature rise in the Pacific countries, compared to the results obtained from global models such as those compiled in MAGICC/SCENGEN version 5.3.v2. This is because global models have coarser resolutions and are incapable of capturing relatively small areas/islands and their topographies. Downscaling allows for a finer resolution with a better representation of local terrain. This is a more meaningful result in the context of local climate impacts.

II. The El Niño-Southern Oscillation

ENSO is instrumental to the understanding of climate change in the Pacific (Box 4.1)). Although the mechanisms that cause ENSO events are still under study, the variation in SST is believed to be their key driver. This section investigates SST anomalies in the following four well-known Niño regions: Niño 1.2 (90°W-80°W, 10°S-0), Niño 3 (150°W-90°W, 5°S-5°N), Niño 3.4 (170°W-120°W, 5°S-5°N), and Niño 4 (160°E-150°W, 5°S-5°N), and then calculates changes in ENSO events (El Niño and

Figure 4.3: Distribution of SST Anomalies, A1B and A2 Scenarios



Source: ADB study team.

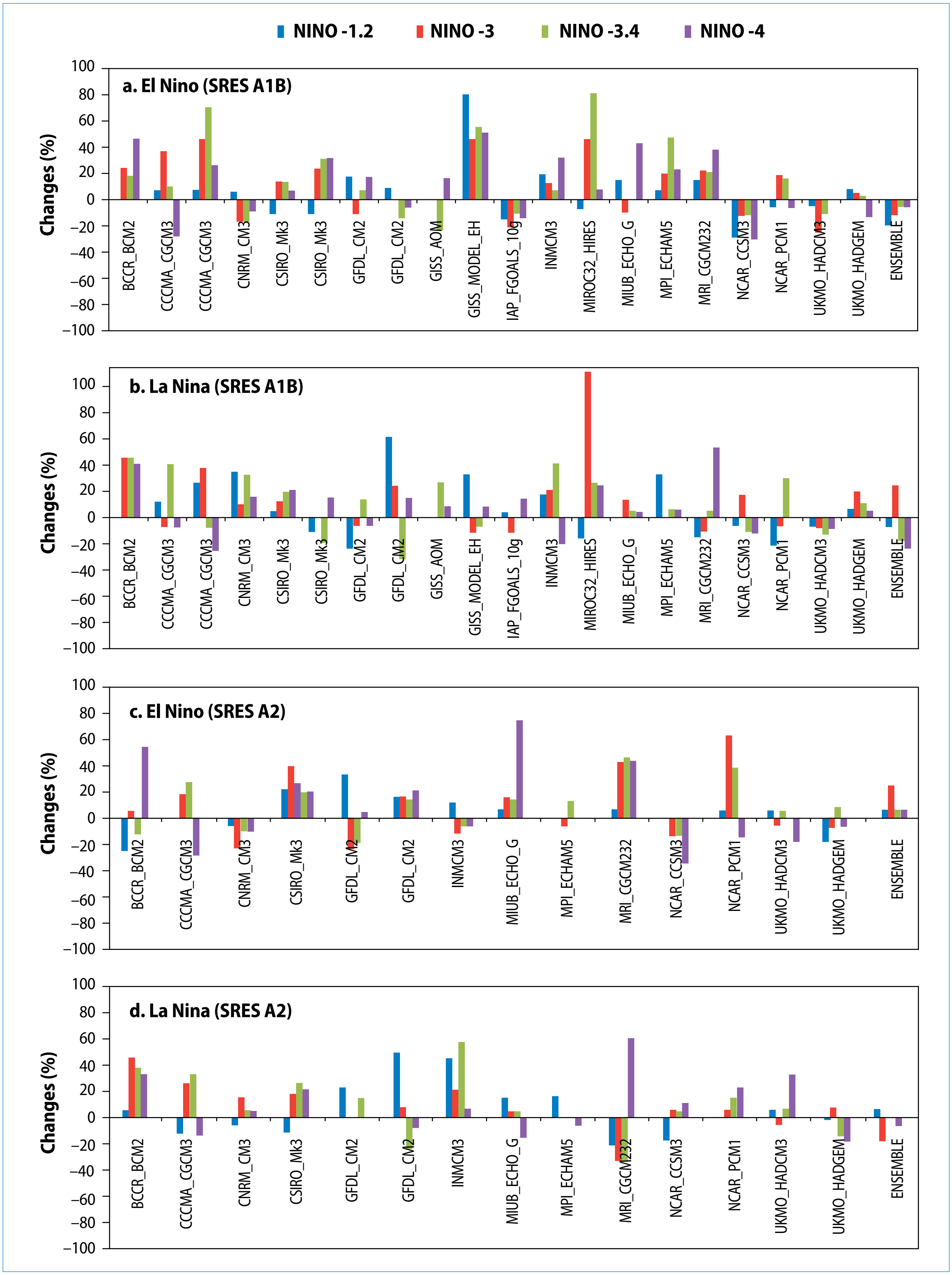
La Niña) as a result of climate change. ENSO events and ENSO conditions are defined in this study as prolonged SST anomalies (positive for El Niño—ocean warming—and negative for La Niña—ocean cooling) that exceed their standard deviations for at least a 5-month period.

The probability density functions of SST anomalies in the four Niño regions are constructed for A1B scenario based on 20 GCMs ensemble, and for A2 scenario based on 14 GCMs ensemble, relative to the 1901–2000 baseline from the 20C3M simulations[12] (Figure 4.3). Under A1B scenario, standard deviations of the future SST anomalies appear to be slightly lower than the 1901–2000 baseline. This indicates that the intensity of ENSO could be lower under a scenario that emphasizes a balanced energy source and shifts away from the current fossil-fuel dependent path. In contrast, under A2 scenario, the standard deviations of SST anomalies are higher than that of the baseline and A1B.

Figure 4.4 presents the percentage changes of the frequency of ENSO events as a result of climate change under A1B and A2 scenarios relative to the baseline. The analysis of A1B scenario based on an ensemble mean appears to correspond to the shifts in the distributions of SST anomalies. The A1B scenario observes potential decreases in the frequency of ENSO events in all Niño regions, except for La Niña in Niño-3 region. However, the A2 scenario produces a consistent increase in the number of El Niño events in all Niño regions, but not of La Niña's.

[12] Multiple ensemble climate simulations have been produced for the IPCCC AR4. Along this effort, a number of coupled ocean-atmosphere models have generated outputs for a variety of climate change scenario. The 20C3M, initiated as a pilot project by the CMIP5 to contribute to the IPCC AR4, also generated a climate change scenario. The scenario produced by 20C3M is often used to initialize simulations of future climate scenarios.

Figure 4.4: Climate Change Impact on ENSO Events



Source: ADB study team.

The impacts of climate change on ENSO events simulated from individual GCMs vary in terms of magnitude and direction. Most GCMs agree and predict an increase in the frequency of both El Niño and La Niña events in the future (Figure 4.4). A number of models suggest an increase of over 40% in ENSO events under both climate scenarios, while a few indicate an increase of as high as 80% in such events.

III. ENSO Rainfall

The analysis based on a number of GCMs suggests that the frequency of ENSO events is likely to increase in the future. This section investigates future ENSO-rainfall linkages based on the climate downscaling using RegCM3. Such analysis is important because ENSO plays a major role in the climate change process in the Pacific region. The correlation between SST anomalies in the Niño regions (ENSO indices) and rainfall over the six countries and surrounding water is estimated using a coefficient regression method. The coefficients indicate the magnitude of the relationship under the A1B scenario in comparison with the 1990 baseline. Note that all results below are presented for 1°C.

A. Fiji

Historical patterns suggest that rainfall in Fiji may be negatively correlated with ENSO indices. A negative relationship is found significant between SST anomalies and the rainfall in the western tropical Pacific, particularly the Niño-4 region over the western part of Viti Levu and Kadavu (Figure 4.5a). During the 1981-2000 period, an increase in 1°C of SST anomalies is estimated to reduce rainfall by up to 1.8 millimeter (mm)/day (54 mm/month) in this southwestern region of Fiji during El Niño. The correlations were found to be insignificant in the Central region (eastern part of Viti Levu) and over the Northern region (most of Vanua Levu).

However, around the mid-century, ENSO is expected to influence rainfall patterns over some parts of Fiji differently from its historical patterns. Strong positive correlations between ENSO indices and rainfall are found over Vanua Levu, particularly its northern coast, and over the eastern coast of Viti Levu (Figure 4.5b). In 2050, these regions are expected to experience wetter conditions (1.5 mm/day more rainfall) during El Niño, and drier conditions during La Niña. An increased number of tropical cyclones are expected to occur as a consequence of stronger El Niño-rainfall linkages, and this could lead to higher probability of flooding (Kostaschuk et al. 2001; Chand and Walsh 2009). The same trend is projected to continue towards 2070, albeit with smaller impacts than those in 2050 (Figure 4.5c).

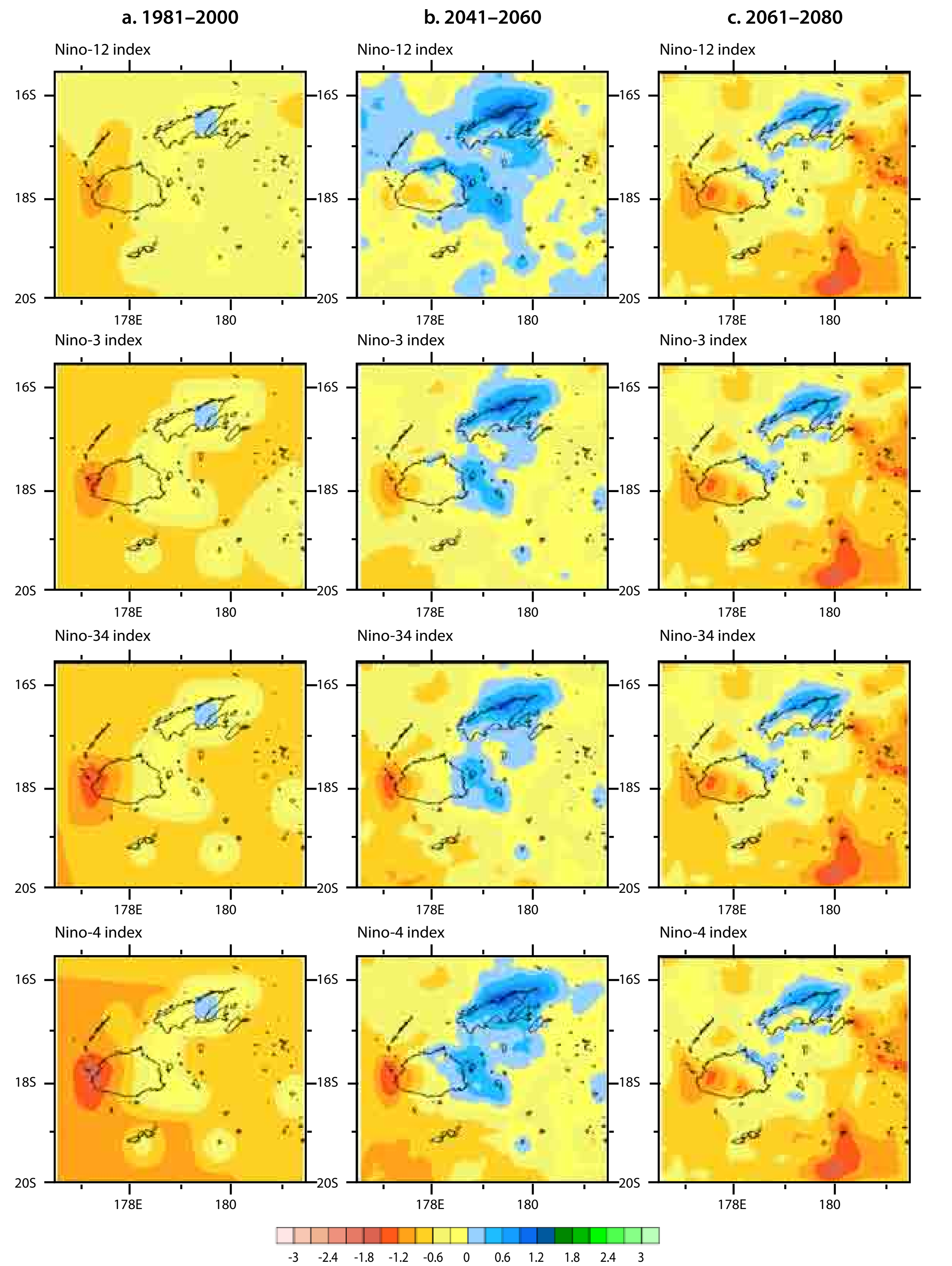
B. Papua New Guinea

El Niño conditions have reduced rainfall over PNG during the 1981–2000 period, particularly along the southern coast of the Central and Gulf areas, the Western province, and the southern coast of New Britain (Figure 4.6a). The northern part of the main island was less affected by ENSO events. By 2050, increased SST anomalies are projected to result in drier conditions covering a larger area of PNG (Figure 4.6b). The downscaling suggests that in 2050, up to 3 mm/day difference of rainfall is possible with a 1°C variation in SST around the eastern and central tropical Pacific oceans. These future ENSO events are likely to cause more extreme conditions, potentially leading to droughts during El Niño and floods during La Niña. Nevertheless, it appears that the northern coast of the main island would remain unaffected. A similar trend is projected to continue towards 2070, but with less extreme conditions (Figure 4.6c). The East and West New Britain and New Ireland would be affected negatively and strongly by Niño-1.2 index under the future climate.

C. Samoa

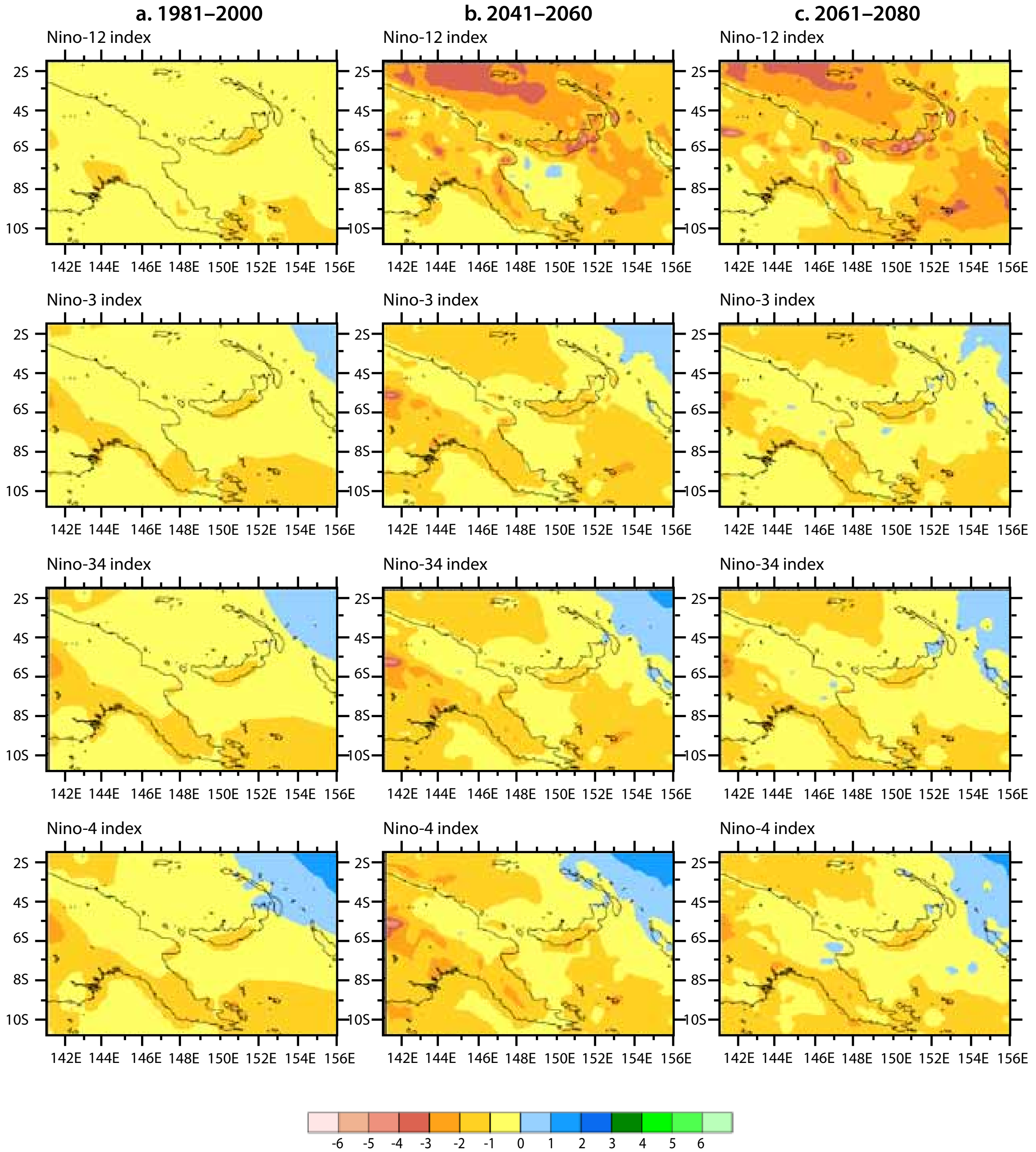
Samoa being adjacent to the boundary of the central tropical Pacific region, its rainfall variability in the past had been strongly affected by the warming over of the eastern Pacific ocean. The rainfall amount was negatively correlated with Niño-1.2 index, with impact of around 1 mm/day/°C over Upolu (Figure 4.7a). Under its future climate, however, Samoa would experience different effects of ENSO events. By 2050, the negative correlation between SST anomalies and the rainfall would be driven mostly by the climate change in the central Pacific region (Niño-3 and Niño-3.4), and the impact is projected to be stronger in Savai'i (Figure 4.7b). In the longer term, the analysis suggests more extreme conditions

Figure 4.5: ENSO Impact on Rainfall in Fiji: Baseline and A1B (mm/day/°C)



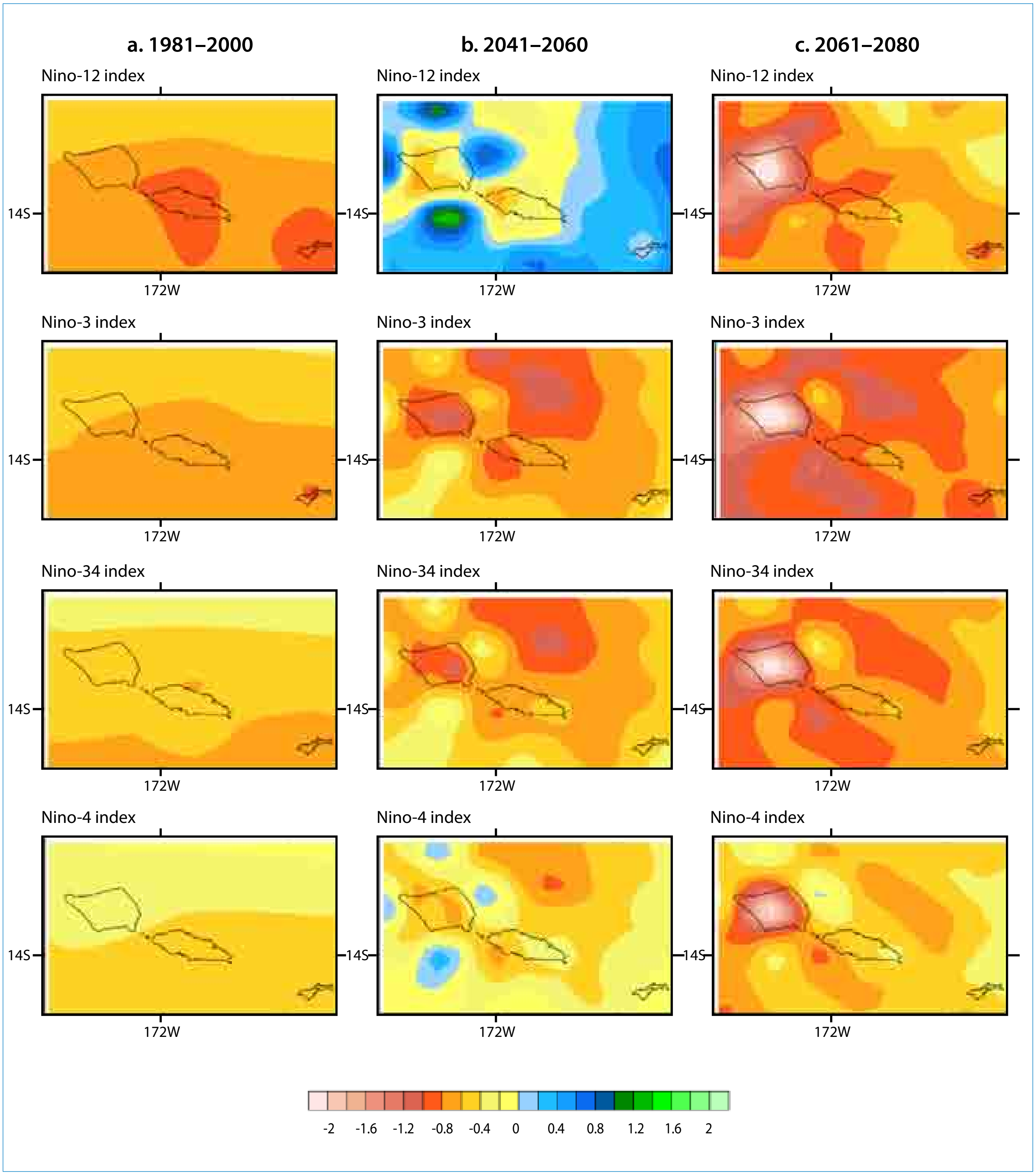
Source: ADB study team.

Figure 4.6: ENSO Impact on Rainfall in PNG: Baseline and A1B (mm/day/°C)



Source: ADB study team.

Figure 4.7: ENSO Impact on Rainfall in Samoa: Baseline and A1B (mm/day/°C)

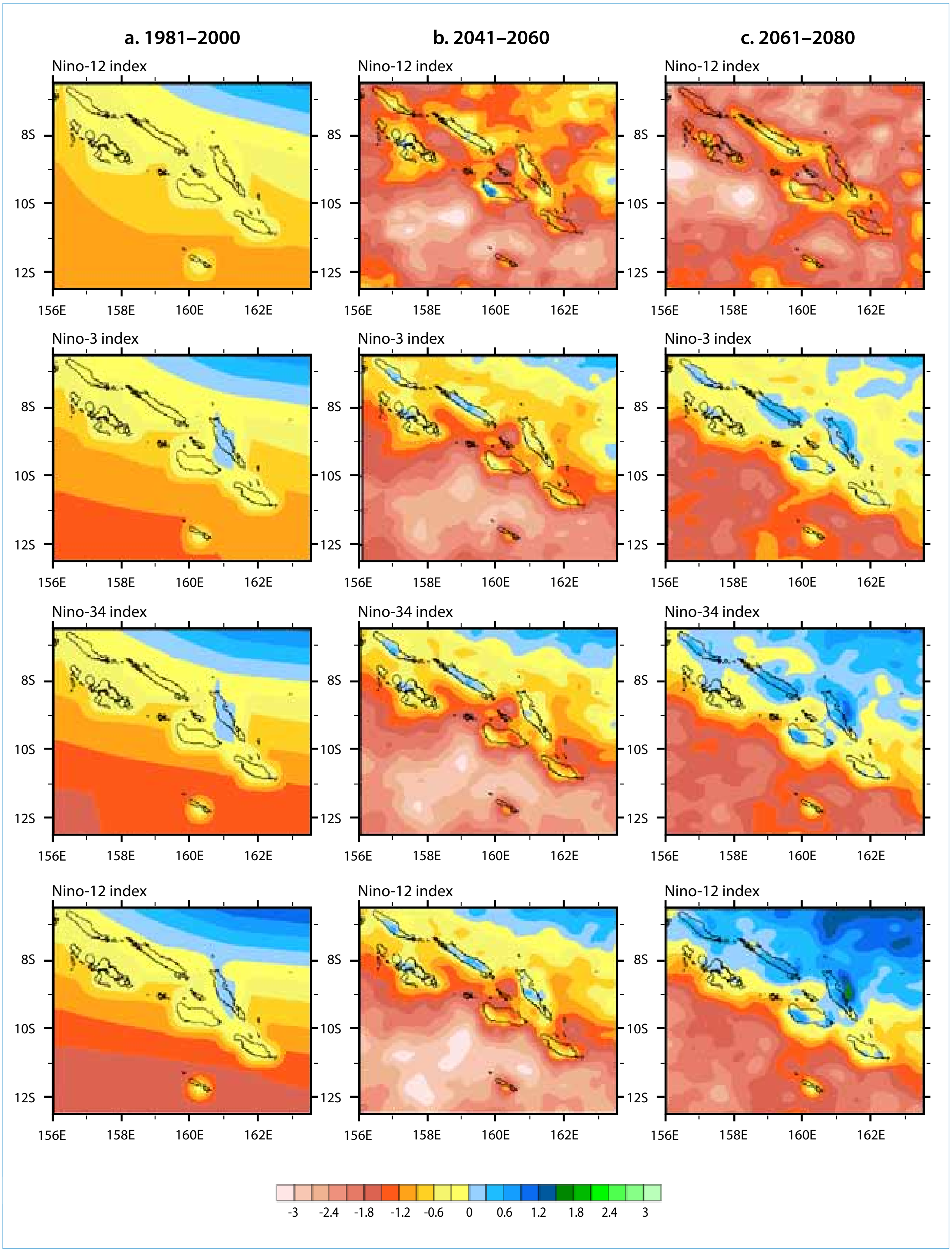


Source: ADB study team.

in both Upolu and Savai'i. By 2070, a 1°C SST change is estimated to induce over the districts of Savai'i an increase of over 2 mm/day of rainfall in the wet season and a rainfall decrease by the same amount during the dry season; this is expected to bring about severe droughts as well as floods (Figure 4.7c).

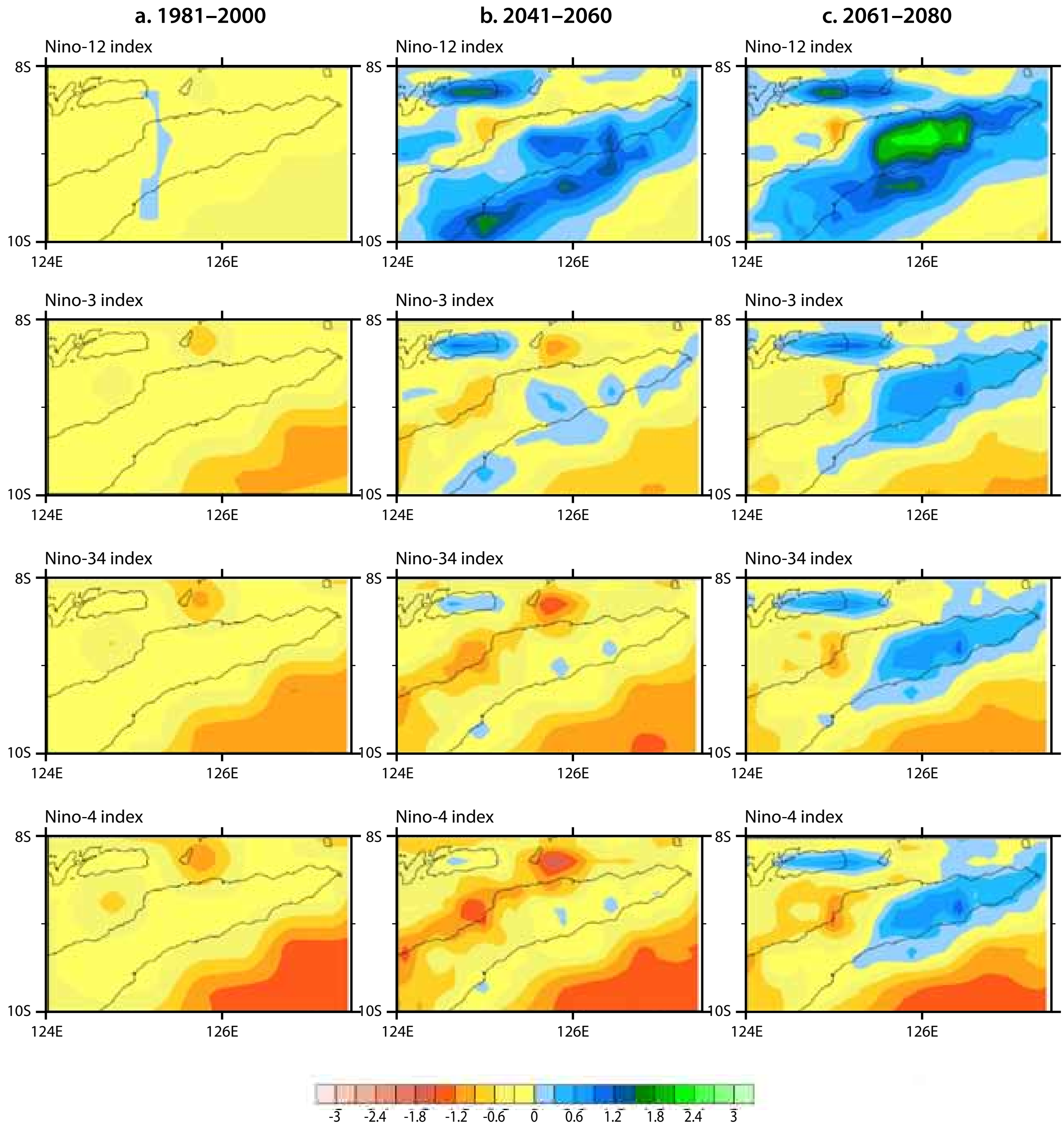
Upolu appears to be less vulnerable to ENSO events compared with Savai'i, but it nevertheless needs to be prepared to cope with harder conditions that potentially can be caused by Niño-3 and Niño-3.4 in the future.

Figure 4.8: ENSO Impact on Rainfall in Solomon Islands: Baseline and A1B (mm/day/°C)



Source: ADB study team.

Figure 4.9: ENSO Impact on Rainfall in Timor-Leste: Baseline and A1B (mm/day/°C)

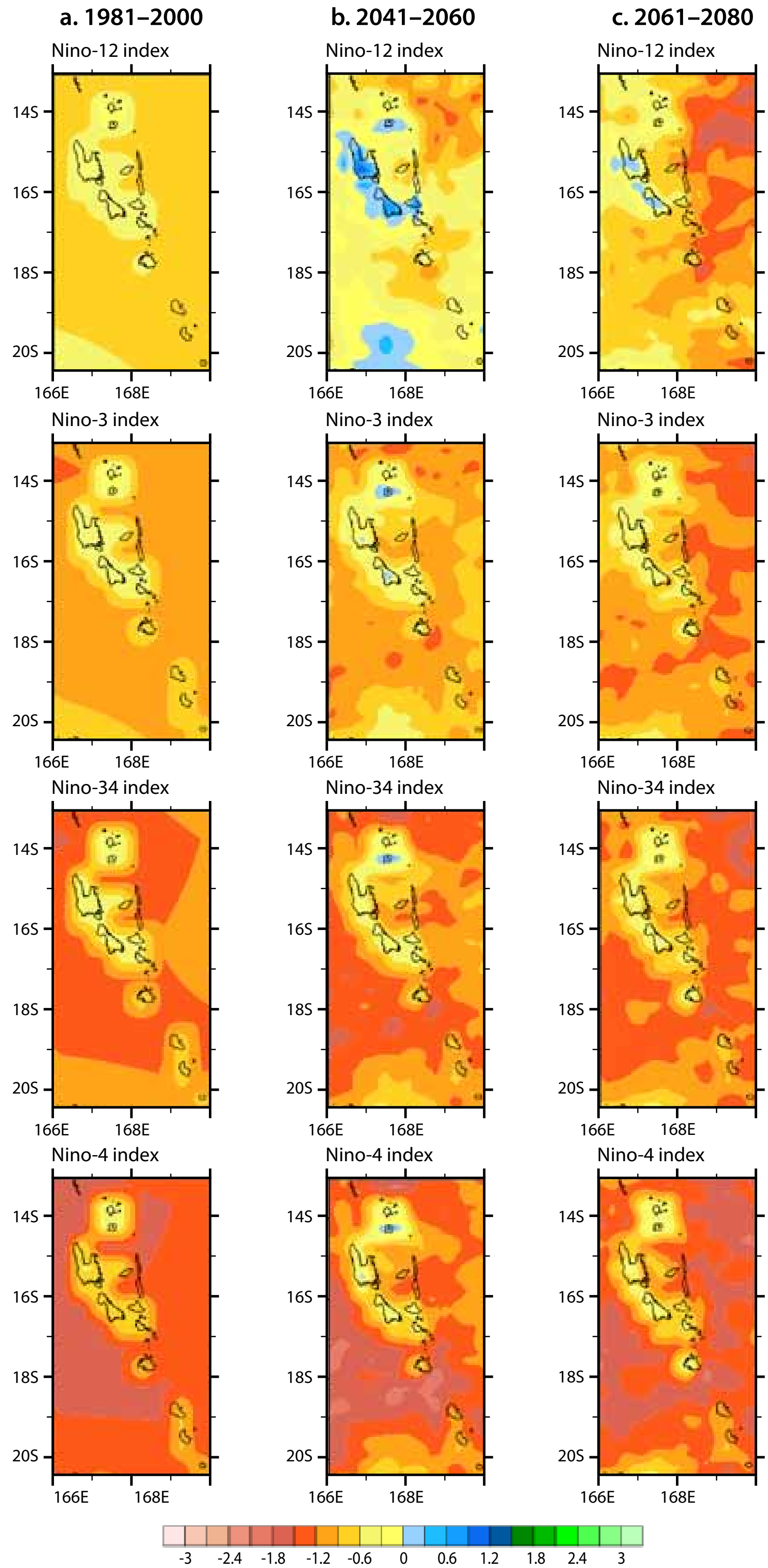


Source: ADB study team.

D. Solomon Islands

The analysis shows that under the baseline, the impact of ENSO events on rainfall over Solomon Islands has been relatively small compared to those in PNG and in Samoa. The south and southwestern islands have been more vulnerable to ENSO events, and the rainfalls in these areas had negative correlations with SST anomalies; on the other hand, the north and northeastern fronts facing the south Pacific oceans appear unaffected by ENSO under the current climate (Figure 4.8a). This Niño-rainfall pattern would shift over the coming decades, however. By 2050, Choiseul and Isabel provinces are expected to experience positive Niño-rainfall

Figure 4.10: ENSO Impact on Rainfall in Vanuatu: Baseline and A1B (mm/day/°C)



Source: ADB study team.

linkage, mostly influenced by the central-western tropical Pacific oceans (Figure 4.8b); Guadalcanal and Makira-Ulawa provinces would see an opposite trend—drier with ocean warming. By 2070, however, the whole of Solomon Islands would experience more extreme situations from all Niño regions (Figure 4.8c).

E. Timor-Leste

Under the baseline, the impact of ENSO events on rainfall over Timor-Leste has been minimal, although it appears that the southern coast has been influenced somewhat by the Western Pacific ENSO (Figure 4.9a). Around the mid-century, an El Niño that is expected to develop from the western tropical Pacific is projected to bring drier conditions (1.0-1.5 mm/day/°C) along the northern coastline, particularly in Bobonaro, Dili, and Liquiçá districts (Figure 4.9b). On the other hand, El Niño developed from the eastern Pacific oceans would cause more rains (0.6-1.2 mm/day/°C) on the southern coastal areas of Ainaro, Cova-Lima, Lautém, and Viqueque, as well as on the inland regions of the Manatuto and Manufahi districts. In 2070, the influence of Niño-1.2 region would amplify and is projected to bring up to 2.2 mm/day/°C magnitude of rainfall impact inland, mostly concentrated in Aileu, Baucau, Manatuto, Manufahi, and Viqueque (Figure 4.9c). El Niño from other tropical Pacific regions are also expected to bring wetter conditions to the eastern part of the country.

F. Vanuatu

Vanuatu's rainfall, which had shown a significant negative correlation with ENSO indices during 1981-2000, is largely influenced by ENSO phenomena developed from the central and western part of the Pacific oceans (Figure 4.10a). However, future climate is projected to change these effects of ENSO events over Vanuatu. While the effects of Niño-3.4 and Niño-4 would weaken over time, the effect of Niño-1.2 is expected to strengthen and would have a relatively strong positive impact on rainfall (around 1.0 mm/day/°C) over Malampa and Sanma provinces, as well as over Gaua Island of Torba province (Figure 4.10b). The positive impacts on rainfall in these areas are projected to weaken by 2070. In 2070, El Niño would cause drier conditions in Penama, Shefa, and Tafea provinces, possibly with approximately 0.9 mm/day less rain as a consequence of 1°C ocean warming (Figure 4.10c).

IV. Extreme weather Events

The Pacific is highly prone to natural disasters that inflict high levels of damage and impact a high proportion of the population (Table 4.1).

The leading cause of damage is windstorms (Table 4.2), far exceeding other leading other sources of natural disasters (Bettencourt et al. 2006). Windstorms, which often are part of cyclones, directly destroy infrastructure, buildings, and agricultural production as well as lead to large

Table 4.1: Selected Disaster Statistics for Countries of the Pacific, 1950–2012

Pacific DMCs	Number of disaster events	Average population affected population when event (%)	Average economic damage in year of event (%)	Average economic damage across all years (% of GDP)	Peak economic damage (% of GDP)
Fiji	49	6.2	1.5	0.0	9.0
Kiribati	4	26.4	n.d.	n.d.	n.d.
FSM	8	5.2	0.9	0.0	6.0
PNG	52	1.0	0.2	0.0	3.1
Samoa	12	19.9	41.6	0.8	161.7
Timor-Leste	8	0.3	n.d.	n.d.	n.d.
Tonga	14	14.6	7.3	0.1	28.7
Tuvalu	6	2.1	n.d.	n.d.	n.d.
Vanuatu	40	7.7	7.4	0.1	125.6

n.d. = no data. Source: Data from EM-DAT, the International Disaster Database and the World Bank.

Table 4.2: Losses from Different Types of Natural Disasters in the Pacific, 1950–2004

Natural Disasters	Number	Reported Fatalities	Population Affected[1]	Reported Losses (in 2004 $ Million)
Windstorms[2]	157	1,380	2,496,808	5,903.90
Droughts	10	0	629,580	137.00
Floods	8	40	246,644	94.80
Earthquakes	17	53	22,254	330.60
Others[3]	15	274	21,520+	60.00
Total Pacific	**207**	**1,747**	**3,416,806+**	**6,526.30**

[1] Fatalities plus total population affected. All data excludes PNG.
[2] Cyclones, tidal surges, and storms.
[3] Landslides, tsunamis, volcano eruptions, wild fires, and epidemics.
Source: Bettencourt et al. 2006.

wave events that further damage coastal resources. Given that weather extremes are directly affected by climate change, it is important to understand the degree to which losses would be exacerbated in the future.

This section examines the possible impacts of climate change on extreme events such as extreme temperature, rainfall, and surface-wind speed. Extreme weather events refer to weather phenomena that occur at the extremes (or edges) of the total range of weather experienced in the past. In this study, they are defined as the 99th percentile (threshold) of the distribution of daily maximum data over the 20-year periods, based on the output of each grid from the downscaling exercise described above. A change of distribution in the future at the same threshold (the current 99th percentile) can be interpreted as a change of exceedance probability (the technical term for the likelihood of exceeding the limit), and can thus be associated with a change of risk due to an extreme event. When the risk of extreme situations looms large, planning to adapt to average outcomes may not be good enough. This section therefore analyzes the most extreme weather outcomes possible in the Pacific countries covered by this study.

A. Fiji

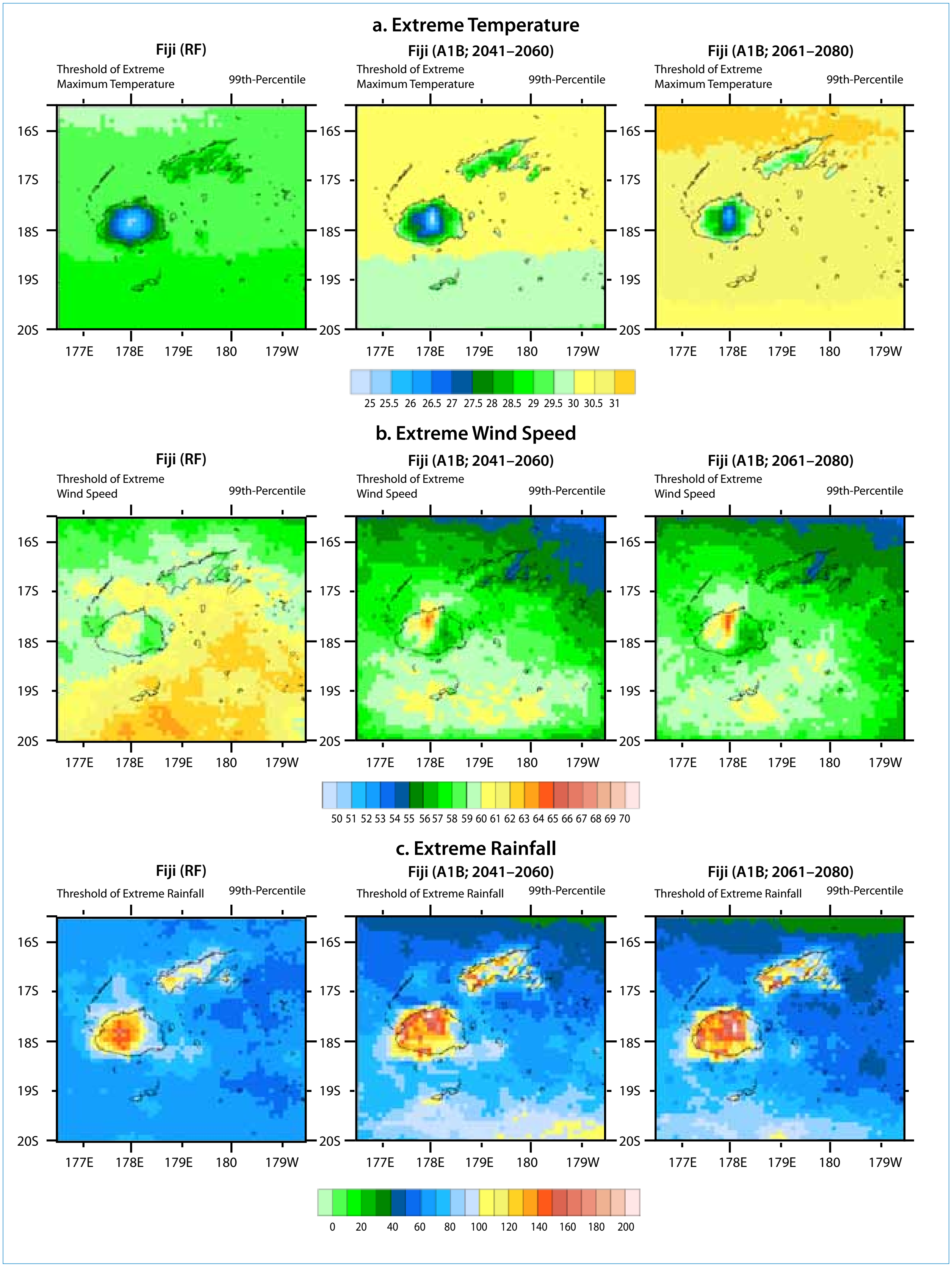
Extreme temperature in Fiji is likely to heighten in the future. In the coastal areas, it is projected to increase from around 29°C during 1981–2000 to 31°C over the period 2061–2080 (Figure 4.11a). In the central and western parts of Viti Levu, which are relatively elevated, extreme wind speed would increase from the current 60 km/h to a high of 66 km/h by 2070 (Figure 4.11b). The wind speed in the ocean around Fiji indicates a higher likelihood of gale in the future. Future rainfall is projected to intensify and expand from the western parts to cover a larger area of both Viti Levu and Vanua Levu. In Western Viti Levu, extreme rainfall registered contemporarily at 160 mm/day is expected to increase to 200 mm/day and extend to its northeastern part (Figure 4.11c). Over the ocean north of Fiji, the combination of increased exceedance probability at the current threshold of near-surface wind speed, rainfall, and temperature indicates a greater probability of cyclogenesis[13] and tropical cyclones in the country.

B. Papua New Guinea

The warmest areas in PNG appear to be along the southern coast of the main island (Gulf and Central province including Port Moresby), Western province, and East and West Sepik. This pattern is expected to continue under future climate. The exceedance probability of temperature at the current 99th percentile (around 39°C) is projected to increase in the future, and could reach 42°C in these regions (Figure 4.12a). No significant change is expected over time in terms of extreme wind speed; however, it would be higher over the ocean than over land areas (Figure 4.12b). The 60 km/h wind speed in the sea around PNG would increase the probability of storm and high wave in PNG. From 2061–2080, extreme rainfalls at 180 mm/day could occur and cover a larger area of PNG. Parts of the coastlines in Gulf and Central province, which currently have extreme rainfalls, would become

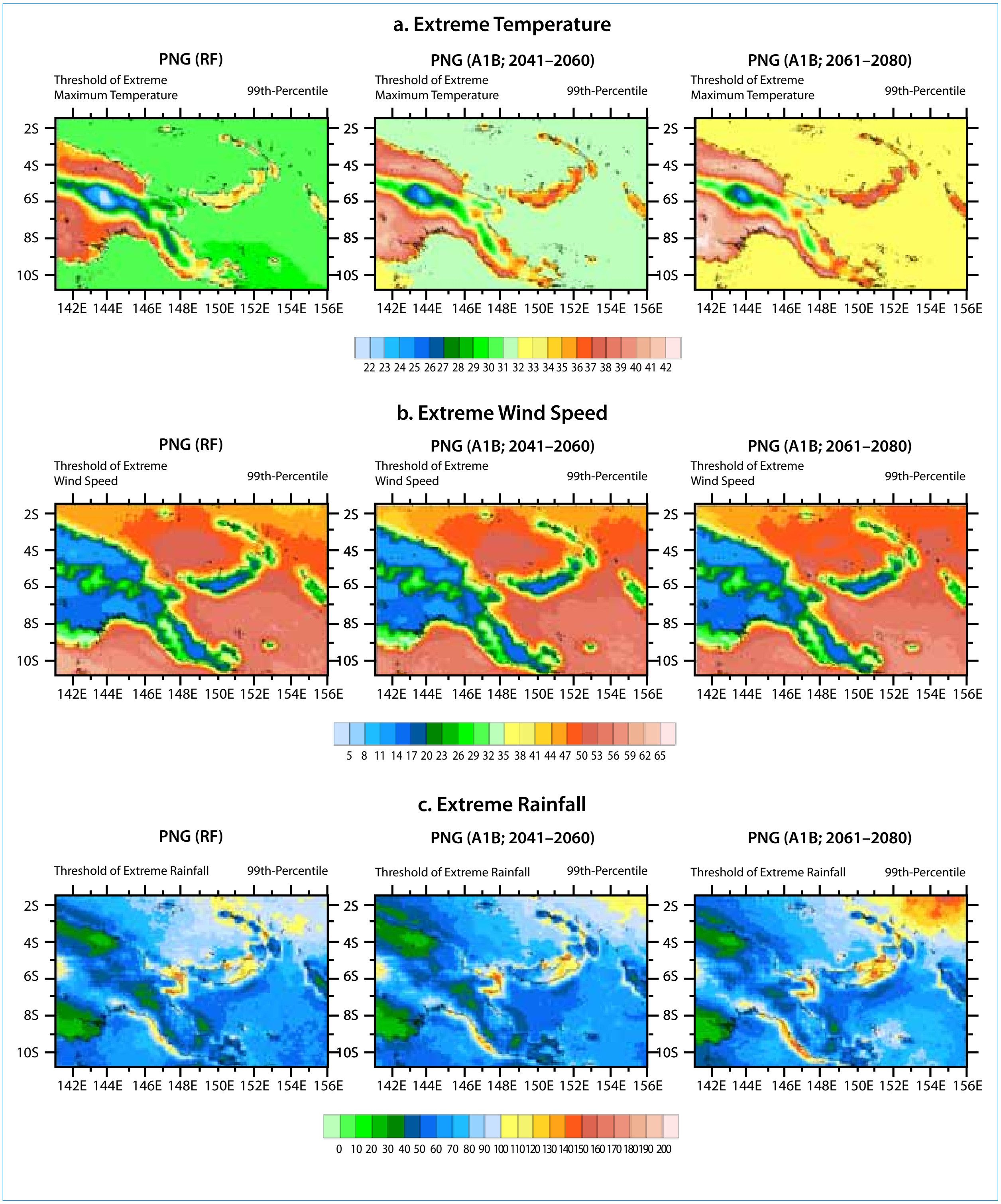
[13] Cyclogenesis refers to the "growth of a tropical depression, then a tropical cyclone, from a pre-existing mesoscale convective storm" (Frank 1987).

Figure 4.11: Extreme Temperature, Wind Speed, and Rainfall in Fiji



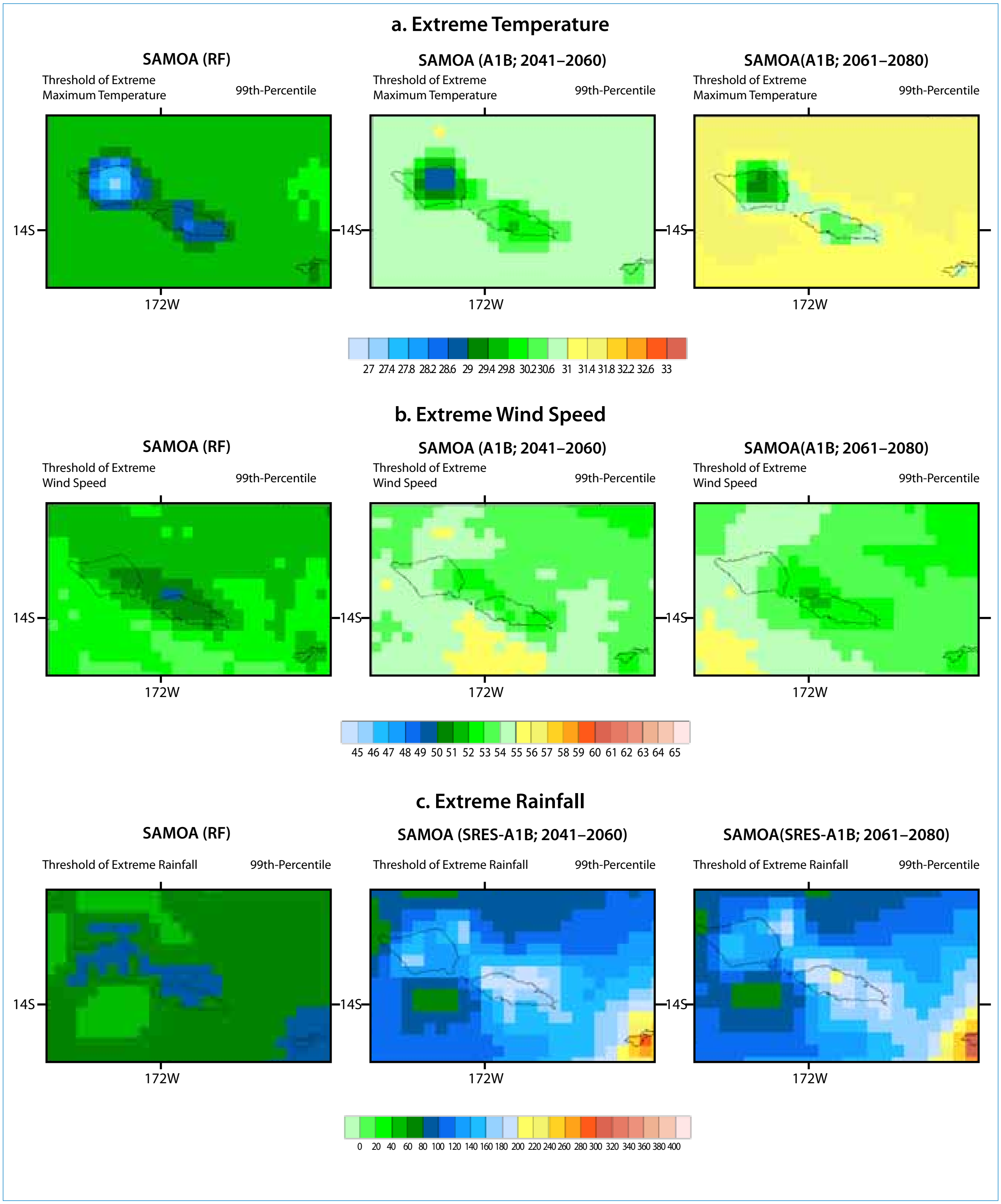
Source: ADB study team.

Figure 4.12: Extreme Temperature, Wind Speed, and Rainfall in PNG



Source: ADB study team.

Figure 4.13: Extreme Temperature, Wind Speed, and Rainfall in Samoa



Source: ADB study team.

even more vulnerable to them (Figure 4.12c). Other areas vulnerable to future extreme rainfalls are the coastal zones of Morobe province and the central area of New Britain.

C. Samoa

In Samoa, extreme temperature is projected to increase from 29°C during 1981–2000 to as high as 32°C by 2070 under future climate (Figure 4.13a). The warmest areas are around the coastal areas of Savai'i and Upolu, which have relatively low elevation levels. Extreme wind speed would increase slightly in the future, from 52 km/h under the baseline to 55 km/h under the future climate scenario (Figure 4.13b). The analysis projects faster wind speed of around 57 km/h in the ocean to the south of Samoa, which suggests the chance of gale potentially causing high wave. The districts of Upolu would experience more extreme rainfall than those of Savai'i. Heavy rainfall in Upolu is expected to increase from 96 mm/day in 1990 on average to nearly 200 mm/day by 2070 (Figure 4.13c).

D. Solomon Islands

The baseline data shows that extreme temperature in Solomon Islands was around 34°C. It is projected to rise to 35.5°C by 2050 and further to reach a high of 38°C by 2070; the warmest areas would be the Western province, particularly on Kolombangara Island (Figure 4.14a). The downscaling exercise suggests that Solomon Islands would not suffer from extreme wind speed over its land area in the future (Figure 4.14b), and that the extreme wind speed over the ocean would decline towards the year 2070. This indicates a lower probability of future tropical cyclones around the country under the A1B climate scenario as opposed to the baseline. Although the amount of extreme rainfall is projected to increase outside the west coasts of Guadalcanal, Makira, and Malaita around 2050, it seems that the patterns of extreme rainfalls over land areas of the country would be unaffected by future climate (Figure 4.14c).

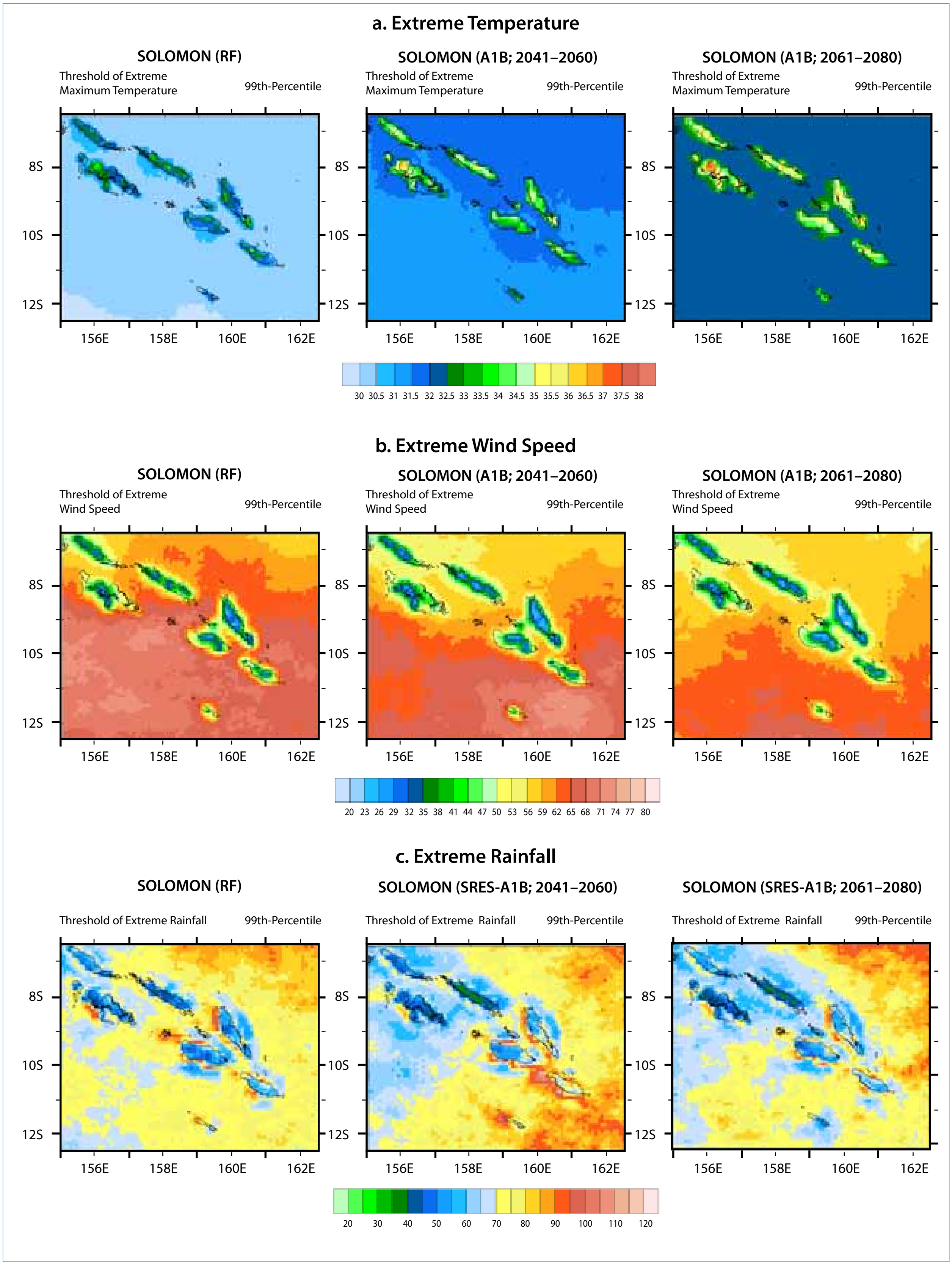
E. Timor-Leste

There is a large variation in terms of extreme temperature across different parts of Timor-Leste. Under the baseline climate scenario, it ranged from 29°C around the coast of Cova-Lima in the south to 40°C on the coast of Bobonaro in the north (Figure 4.15a). There would be an increase of extreme temperature over time up to the year 2070. The warmest area would continue to be in Bobonaro and the temperature could reach as high as 44°C; this is the most extreme temperature by 2070 among the six countries considered in this chapter. As to the extreme wind speed patterns, they are unlikely to change in the future over the land areas of Timor-Leste (Figure 4.15b). However, the country would face strong wind in the ocean (around 64 km/h) that could bring tropical storms. Apart from being the hottest, the country is also the driest among the six countries, with a baseline rainfall of only 72 mm/day (Figure 2.15c). There would be no significant change of rainfall patterns under the future climate, although Timor-Leste would experience slightly more rainfall.

F. Vanuatu

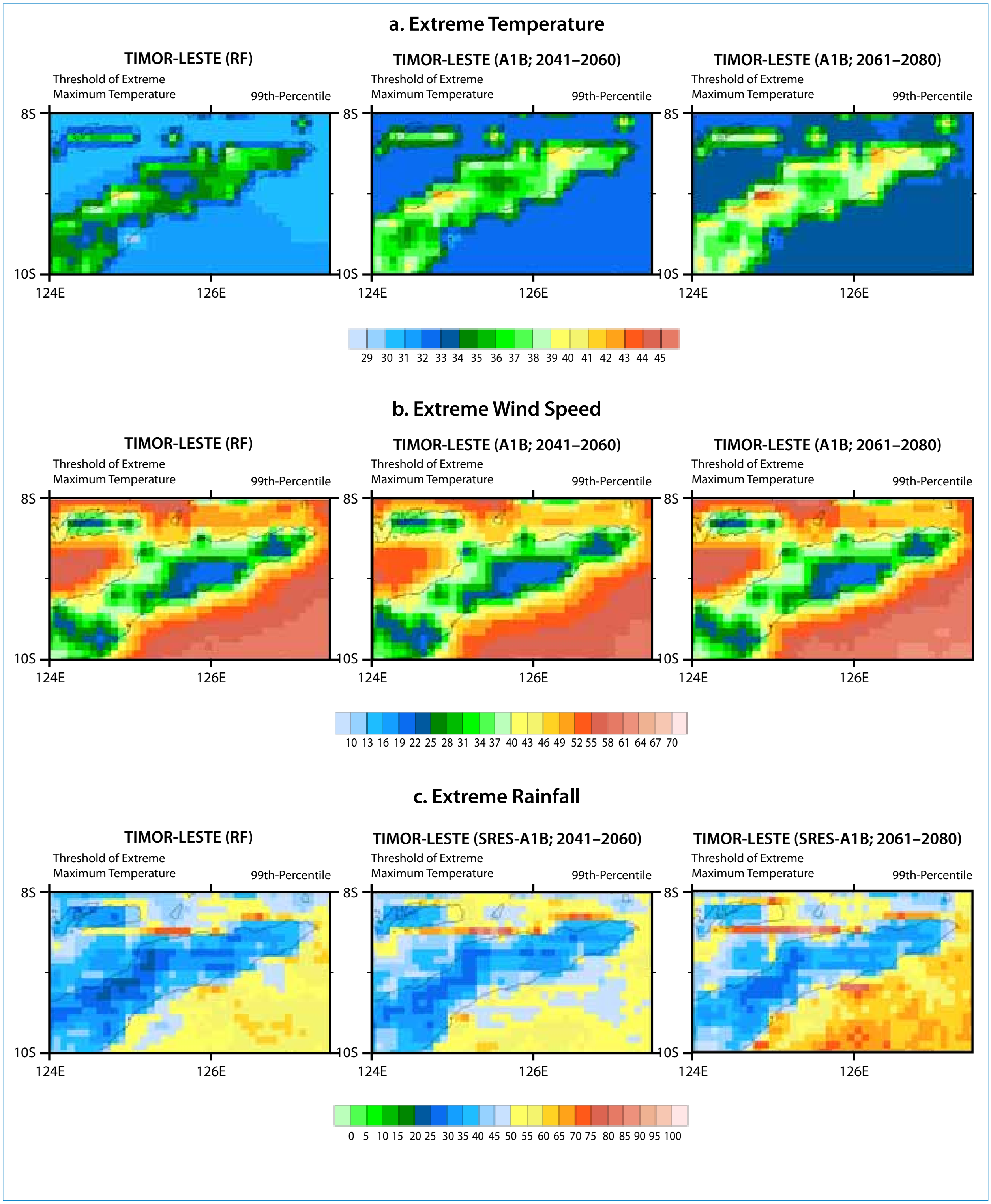
The exceedance probability of extreme temperature over Vanuatu would increase significantly over land and ocean under future climate. Over land areas, the extreme temperature is projected to increase from 32°C under the baseline scenario to 38°C by 2070 (Figure 4.16a). Malampa, Penama, and Sanma are likely to experience more extreme temperature than the smaller islands. Extreme wind speed would likely remain unchanged under future climate scenarios (Figure 4.16b). Even the strongest wind over land areas is expected to be below 40 km/h in the period of 2061-2080 under the A1B. However, wind speed over the ocean could reach 64 km/h, putting Vanuatu at risk of tropical storms. Extreme rainfall is currently around 115 mm/day. Unlike in other countries, extreme rainfall is expected to decline in Vanuatu under future climate scenarios (Figure 4.16c). The wettest condition would only be around 70 mm/day by 2070, suggesting a much drier weather in the future for Vanuatu.

Figure 4.14: Extreme Temperature, Wind Speed, and Rainfall in Solomon Islands



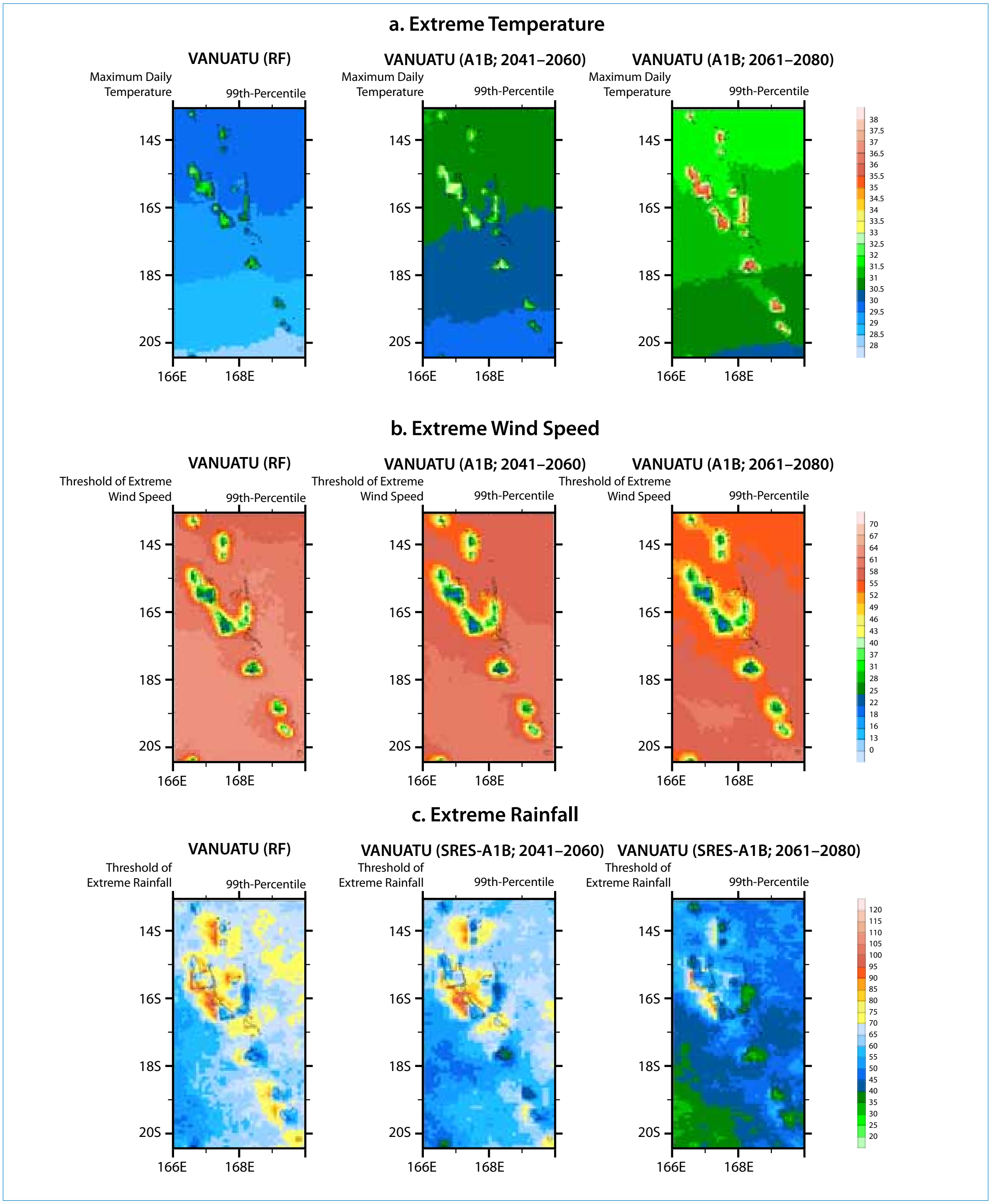
Source: ADB study team.

Figure 4.15: Extreme Temperature, Wind Speed, and Rainfall in Timor-Leste



Source: ADB study team.

Figure 4.16: Extreme Temperature, Wind Speed, and Rainfall in Vanuatu



Source: ADB study team.

V. Cyclone Risk

While the previous analysis offers useful information in terms of expected temperature and rainfall volatility, its ability to identify changes in cyclone risk is limited in comparison with other cyclone identification algorithms. However, recent complementary work has therefore focused more directly on using an array of methods to detect cyclone formation in GCMs.

Changes in tropical cyclone frequency for the Pacific region have been assessed by the Australian Bureau of Meteorology and CSIRO (2011) using 14 GCMs under the A2 scenario to compare the 1980–1999 period with 2080–2099. The GCMs are run with the Conformal Cubic Atmospheric Model (CCAM) at 60 km grid cell resolution, supplemented with several detection algorithms for cyclone formation, for three "basins" of the Pacific region. This analysis finds results consistent with prior global modeling studies that project a decrease in tropical cyclone frequency under climate change (Walsh et al. 2012), with many of the findings indicating decreases of cyclone frequency of 30% to 70%, but with large variation among the models and cyclone identification algorithms (Table 4.3).

Changes in cyclone intensity were also modeled by the Australian Bureau of Meteorology and CSIRO (2011). Using the Maximum Potential Intensity index from the Genesis Potential Index methodology for cyclone interpretation, intensity is expected to fall based on 9 out of 14 GCMs, while the remaining five show very small increases. However, at the same time, the analysis finds in most simulations an increase in the proportion of storms with wind speeds above the current 90th percentile maximum wind speed.

Other results are variable. Several older studies with similar time periods under the A1B and related scenarios, which use statistical or dynamical downscaling (Vecchi and Soden 2007; Oouchi et al. 2006, and Walsh et al. 2004), have found mixed results from a 22% decline in maximum wind speed to a 26% increase.

While the details of the projections available to date are often contradictory, the preponderance of recently available evidence suggests that cyclone risk would decline overall for the region, with the

Table 4.3: Changes in Expected Frequencies of Cyclones in Basins of the Pacific, 2011

GCM	Southeast basin		Southwest basin		North basin	
	Most optimistic cyclone algorithm	Most pessimistic cyclone algorithm	Most optimistic cyclone algorithm	Most pessimistic cyclone algorithm	Most optimistic cyclone algorithm	Most pessimistic cyclone algorithm
CSIRO-Mk3.5	–65	10	–70	50	–80	10
ECHAM5/MPI-OM	–50	25	–80	15	–80	5
GFDL-CM2.0	–70	–20	–60	–5	–45	5
GFDL-CM2.1	–50	–10	–70	–5	–50	–5
MIROC3.2	–90	–75	–85	–80	–85	–50
UKMO-HadCM3	–55	–30	–55	10	–30	15
BCCR-BCM2.0	–90	–5	–90	10	–100	15
CGCM3.1	–20	30	–10	30	–10	–5
CNRM-CM3	–20	–35	–20	10	–30	–5
MRI-CGCM2.3.2	–25	0	–15	–5	0	0
CSIRO-Mk3.0	–50	0	–55	0	–65	0
UKMO-HadGEM1	–5	0	5	0	15	0
IPSL-CM4	–20	0	–15	0	–20	0
ECHO-G	–35	0	–25	0	–25	0
ENSEMBLE	–60	–6	–65	0	–45	–5

Source: Australian Bureau of Meteorology and CSIRO. 2011.

Table 4.4: Estimates of Sea-Level Rise Relative to 2010 (meters)

Pacific DMCs	2050			2100		
	Extrapolation of historical Aviso data	GCMs Low	GCMs High	Extrapolation of historical Aviso data	GCMs Low	GCMs High
Fiji	0.283	0.328	0.628	0.628	0.738	1.413
PNG	0.301	0.348	0.644	0.667	0.783	1.449
Samoa	0.212	0.260	0.556	0.470	0.585	1.251
Solomon Islands	0.431	0.476	0.772	0.956	1.071	1.737
Timor-Leste	0.226	0.272	0.572	0.501	0.612	1.287
Vanuatu	0.257	0.304	0.604	0.571	0.684	1.359
Cook Islands	0.175	0.224	0.520	0.389	0.504	1.170
Kiribati	0.057	0.108	0.408	0.126	0.243	0.918
RMI	0.245	0.292	0.592	0.544	0.657	1.332
FSM	0.384	0.428	0.724	0.853	0.963	1.629
Nauru	0.259	0.308	0.604	0.574	0.693	1.359
Palau	0.380	0.424	0.720	0.843	0.954	1.620
Tonga	0.245	0.292	0.588	0.543	0.657	1.323
Tuvalu	0.242	0.288	0.588	0.537	0.648	1.323

Source: As reported by Hartari et al., 2011 for Pacific Island Countries based on satellite altimetry data and the results of seven GCMs.

diminishing frequency of cyclones; there is little evidence to suggest that the intensity would increase. Moreover, the locus of intensive cyclone activity is projected to move away from the equator, where many of the countries in the region are located (Australian Bureau of Meteorology and CSIRO 2011). This is one of the few predicted potential positive impacts of climate change, which may help offset the primary natural disaster risk for this part of the world.

VI. Sea-Level Rise

Given the number of low lying atolls in the Pacific region, large potential risks are posed by sea-level rise resulting from thermal expansion of the oceans and melting of land-based ice as the climate warms up. During the 20th century, the average mean relative sea-level around the Pacific region had increased at the rate of 0.77 mm annually, although the rate of rise had been variable across locations due to local meteo-oceanographic factors and vertical land movement (IPCC 2007). For example, based on tidal gauge observations on the atolls of Funafuti, Tuvalu (Western Pacific), an increase in sea level of 2.0 ± 1.7 mm per year was observed (Church et al. 2006). In areas near PNG, sea level increased by as much as 30mm per year, with the highest rate of increase observed during ENSO events.

To update these values, altimetry data from Aviso multiple satellite-merged estimates collected between 1992 and 2009 were applied. With these data, sea-level trends were estimated according to block averaged areas for each Pacific country, and trends were forecast linearly to 2050 and 2100. To supplement this historical analysis, seven GCMs (GISS-AOM, MRI-CGCM, CGCM-T47, GISS-ER, MIROC-HI, MIROC-MED, and MIUB-ECHO) were run under the A1B emissions scenario to project future trends to 2050 and 2100, under the assumption that such trends are linear.

Table 4.4 presents sea-level changes identified under different GCMs and historical extrapolation. The sea-level projection by 2050 under the A1B scenario ranges between 0.11 meters (m) in Kiribati and 0.77 m in Solomon Islands. By 2100, sea level is projected to more than double in all countries with a similar distribution of changes among countries, and many GCMs projected estimates of over 1 m for all countries except Kiribati. The historical estimates based on Aviso appear to mirror closely the lowest values reported from the seven GCMs.

Table 4.5: Estimates of Land Area Inundated Relative to 2010

Pacific DMCs	Area (km2)		% of land area	
	2050	2100	2050	2100
Fiji	0.3	1.4	0.002	0.008
PNG	10.8	15,930.3	0.002	3.426
Samoa	0.5	0.7	0.016	0.023
Solomon Islands	8.0	79.3	0.029	0.286
Timor-Leste	0.4	1.2	0.003	0.008
Vanuatu	1.0	1.8	0.008	0.014

Source: As reported by Hartari et al. 2011 for Pacific countries based on the mean sea-level rise from seven GCMs.

Other short-term projections for sea-level rise reported in the region are similar. Lal (2004) projected a rise in sea level of 25 to 58 cm, across the Pacific region, by 2050. The best previous estimate, as reported by many Pacific countries, is that sea level would increase by approximately a meter by 2100. This means that these Pacific countries would face sea level rise at levels significantly higher than the global average estimate of 0.21 to 0.59 m reported in the IPCC's Fourth Assessment Report (IPCC 2007).

The effect of sea-level rise is to increase the inundation of coastal areas. Spatial analysis can enable the identification of land areas that have elevations lying below the expected future sea levels, assuming that land configuration is not changing over time. As an initial indicative analysis, the analysis used the ASTER Digital Elevation Model (DEM) to assess the area to be potentially inundated under the mean reported sea-level rise from seven GCMs. Their analysis finds that inundated area would be less than 0.3% by 2050 in all Pacific countries, and would remain below that level for all Pacific Countries by 2100 except PNG (Table 4.5).

However, the potential for error in the estimates is substantial given that the 95% confidence interval of the ASTER elevation data is 17 meters, while the sea-level rises analyzed are less than 1.5 meters.[14]

Nonetheless, for larger land masses, inundation would increase. Increased seawater inundation in the Pacific region would reduce the availability of water supply, increase coastal erosion and inundation, and contribute to the loss of productive agricultural lands. This has attendant implications to freshwater availability, agriculture, and coastal and marine resources. As a majority of urban populations in the region live in coastal areas, inundation would also likely cause large costs for infrastructure relocation and fortification.

In sum, the Pacific region and all the countries examined more closely in this chapter would be experiencing significantly higher temperatures over the period of analysis. In addition, more rainfall is projected during existing wet seasons, and less rainfall is projected during already dry conditions. Overall, extreme weather events are likely to intensify, with the possible exception of cyclones in specific locations.

The impact of these weather changes on the key economic sectors of the Pacific countries will be assessed in the next chapter.

[14] Coastal land areas are unlikely to have illogical negative elevation values in the DEM, and this, in the context of the error margin, probably biases coastal elevation data points upwards and the assessed extent of inundation downwards. To predict inundation more accurately, more precise DEMs based on Laser Imaging, Detection and Ranging (LIDAR) are needed, so that the confidence intervals on elevation data are smaller than the expected sea-level rises analyzed.

References

Australian Bureau of Meteorology and CSIRO, 2011. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 1: Regional Overview. Volume 2: Country Reports. 288 pp.

Bettencourt, S. et al. 2006. *Not If, But When: Adapting to Natural Hazards in the Pacific Islands Region -- A Policy Note*. World Bank, Washington, D.C., US.

Chand, S.S. and K.J.E. Walsh. 2009. Tropical cyclone activity in the Fiji region: Spatial patterns and relationship to large-scale circulation. *Journal of Climate*. 22. 3877–3893.

Church, J.A., White, N.J. and J.R. Hunter. 2006. Sea-level rise at tropical Pacific and Indian Ocean islands. *Global and Planetary Change*. 53. 155–168.

Frank, W.M. 1987. Tropical cyclone formation. In Elsberry et al. (eds). *A Global View of Tropical Cyclones*. Marine Meteorological Program, Office of Naval Research: Monterey, CA.

Hartari, I.F., Dasanto, B.D. and S.F. Muin. 2011. Adaptation and impact of current and future climate variability on water sector. In *Final Report: The Assessment of Economics of Climate Change in the Pacific*. Draft report submitted to ADB by CCROM, Bogor, Indonesia.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007. The Physical Science Basis. Summary for Policymakers*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Secretariat. Switzerland.

Kostaschuk R., Terry, J. and R. Raj. 2001. Tropical cyclones and floods in Fiji. *Hydrological Sciences Journal.* 46:435–450.

Lal, M. 2004. Climate change in small island developing countries of the South Pacific. *Fijian Studies*. 2. 15–31.

Oouchi, K. et al. 2006. Tropical cyclone climatology in a global-warming climate as simulated in a 20 km-mesh global atmospheric model: Frequency and wind intensity analyses. *Journal of the Meteorological Society of Japan*. 84. 259–276.

Vecchi, G.A., and B.J. Soden. 2007. Effect of remote sea surface temperature change on tropical cyclone potential intensity. *Nature*. 450. 1066–1070.

Walsh, K.J.E., McInnes, K.L. and J.L. McBride. 2012. Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific—A regional assessment. *Global and Planetary Change*. 80-81. 149–16.

Walsh, K.J.E., Nguyen, K.C. and J.L. McGregor. 2004. Fine-resolution regional climate model simulations of the impact of climate change on tropical cyclones near Australia. *Climate Dynamics*. 22. 47–56.

Chapter 5

SECTORAL IMPLICATIONS OF CLIMATE CHANGE IN THE PACIFIC

This chapter analyzes the vulnerability to climate change of key sectors of the economies in the Pacific. It evaluates available estimates of expected climate change impacts on the region's agriculture sector, particularly in crop production, livestock, and fisheries; the expected effects on tourism based on recent modeling; and the health implications of climate change to the region.

The climate change modeling that projected these sectoral impacts does not take into account interaction effects with other biophysical processes. This study is therefore unable to consider the impact of salinity intrusion and inundation on agriculture, freshwater fisheries, health, and tourism. If these interaction effects are inputted, the estimates of damage may be much higher than projected by this study.

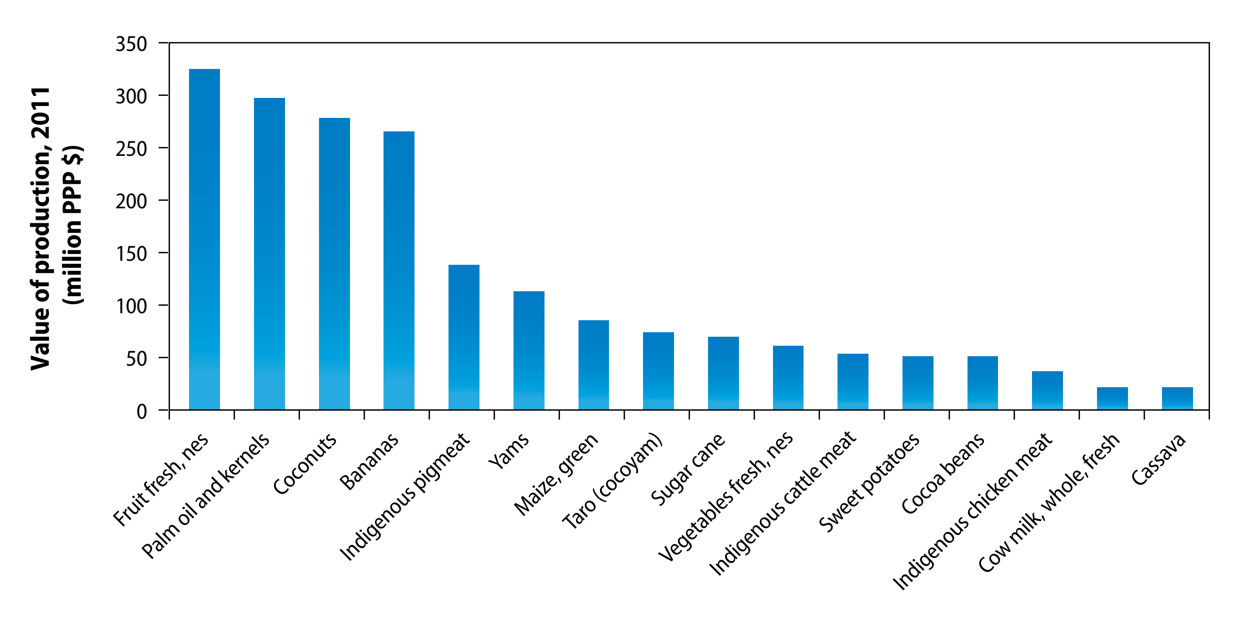
I. Agriculture

Agriculture is essential to the Pacific economies. As indicated earlier in Chapter 2, the Pacific region had 2.5 million hectares of land devoted to agricultural production in 2011, with more than half of the total agricultural area found in PNG, 17% in Fiji, and 15% in Timor-Leste (Table 2.4). The share of the agriculture sector in the total GDP of each Pacific country varies from 3% to 29% (Table 2.2). RMI and Tuvalu devote more than 60% of their total land area to agricultural production, while Kiribati and Tonga devote more than 40%.

Agriculture in the Pacific is dominated by production of perennial crops, such as oil palm, coconuts, bananas, and fruit (Figure 5.1). Livestock, roots and tubers, and maize are also important agricultural products. Among crops, sweet potato, yam, taro, and cassava are considered as staple foods (Wairiu et al. 2012). Sweet potato is the most important subsistence crop in PNG, Solomon Islands, and Vanuatu, while taro and cassava are the most important subsistence crops in Fiji and Samoa (Wairiu et al. 2012).

This diversified agricultural basis makes it challenging to analyze climate change impacts in the Pacific region, and more so because of limited available analytical work that focuses on the modeling of the region's most important crops. It is with this constraint that this study has reviewed the biophysical effects and the available evidence for expected yield impacts from crop-growth modeling. To analyze the vulnerability of the region's principal crops to climate change, the study had to draw on wider evidence regarding their climatic sensitivity.

Figure 5.1: Annual Value of Production of Leading Agricultural Products in the Pacific Region, 2011



nes = not elsewhere specified in this figure, PPP = purchasing power parity.
Source: Data from FAOSTAT, accessed 13 October 2013.

A. Effects of Climate Change on Selected Crop Production

Overall, global warming is expected to negatively impact crop productivity in the Pacific (Barnett and Campbell 2010). Increases in temperature can alter the timing and rate of physiological development, resulting in early maturity and reduced biomass accumulation and yield (Brown and Rosenberg 1999; Challinor et al. 2004; Meza et al. 2008). In addition to the adverse effects of increases in temperature, tropical cyclones can destroy vegetation, crops, orchards, and livestock; damage infrastructure such as canals, wells and tanks; and cause long-term loss of soil fertility from salinity intrusion (Sivakumar 2005). Water-logging and flooding associated with heavy rainfall and tropical storms may lead to crop damage. Tropical cyclones can also wash out arable lands (Sivakumar 2005). Dry desiccating winds and low-moisture conditions brought about by drought can cause large yield losses. The occurrence of pests and diseases is also expected to be affected by climate change (Zhao et al. 2005). Productive coastal lands may be inundated, causing losses in agricultural area, while sea-level rise and changes in storm patterns may cause salinization of freshwater resources needed for crop sustenance (Terry and Chui 2012). At the same time, some negative effects of increased abiotic stress may be mitigated by the carbon-dioxide fertilization effect, which can boost rates of photosynthesis, biomass accumulation, and yield. However, the degree to which this effect can be expected remains unclear (Ainsworth and Long 2005).

Expected yield effects of climate change and the evidence from crop-growth models

Two studies commissioned by ADB (Boer and Rakhman 2011 and Rosegrant et al. 2013) have been conducted to quantify the impacts of climate change on crop yields in the Pacific. Both employ crop-growth modeling in the context of climate forecasts to assess the implications on yields of future changes in temperature, rainfall, and solar radiation. However, neither study incorporates the effects of increased episodic storm events, salinity intrusion, or inundation. As such, the impacts of climate change presented in these two studies may be under-estimates of the true impacts.

The studies are summarized below.

Boer and Rakhman (2011)

Boer and Rakhman (2011) have modeled climate change yield effects for six crop combinations in the Pacific under RegCM3 regional downscaling of the ECHAM5 GCM under the A1B emissions scenario. Climate data are modeled to year 2100, and are contrasted with a "baseline" from 1981 to 2000, with a spatial resolution of 100 to 900 square kilometers (km^2) per grid cell, depending on country. The temporal resolution of the utilized climate data is daily. Crop growth is modeled using the DSSAT model under rainfed and irrigated conditions, using the IIASA world soil database. Yields are modeled with planting dates held constant, using the optimal planting dates for yield. Carbon-dioxide fertilization effects are not incorporated in the analysis. The spatial distribution of crop production is determined using imagery from the Landsat 7 Earth Thematic Mapper Plus.

The largest yield penalties due to climate change are found for sweet potato in PNG and the Solomon Islands, with losses for the former in excess of 50% of yield by 2050. For sugarcane, losses would be relatively small in 2050, but they rise in Fiji by 2070 to a more substantial 7% to 21%. Maize would have moderate losses of 6% to 14% in Timor-Leste and Vanuatu by 2050, with a rise to 14% to 17% by 2070 in the former (Table 5.1).

A key limitation of the Boer and Rakhman (2011) approach is that it is reliant on a single climate model and a single climate scenario. Even within a single scenario, results on key parameters affecting crop growth, such as rainfall and solar radiation, could vary substantially among models. A second limitation is that carbon-dioxide fertilization effects are excluded. This may exaggerate yield losses because such fertilization may offset yield losses from increased abiotic stress. A third limitation is that adaptation options are limited, considering that even in the absence of external interventions for adaptation, farmers may choose varieties better adapted to future climates and may alter other management decisions to respond to climate change. A fourth limitation is that some crops, such as sugarcane in Samoa and maize in Vanuatu, are not among the most important commodities in the country, while the rest may not be representative of the responses of the aggregate agricultural sector considering the prominence of perennial crops and livestock.

Rosegrant et al. (2013)

Rosegrant et al. (2013) modeled an array of crops in PNG, the Solomon Islands, and Fiji under climate change to year 2050, compared with a year 2000 baseline. Four GCMs were used under the A1B scenario: CNRM-CM3, CSIRO Mark 3, ECHAM 5, and MIROC 3.2 medium resolution. Monthly data were downscaled using the approach of Jones et al. (2009), and were adjusted to a 100km grid cell resolution. Monthly averages were modeled on a daily basis using a stochastic weather generator. Ninety runs were performed per model using DSSAT, from which optimal combinations of planting dates and cultivars for each crop were selected for further analysis. Yields were modeled under irrigated and rainfed conditions using soil data from the Harmonized World Soil Database (HWSD ver. 1.1), as reported by Batjes et al. (2009). The spatial distribution of crop production was determined using GLC2000 (Bartholome and Belward 2005),

Table 5.1: Crop-Yield Effects (%) under the A1B Emissions Scenario Relative to a 1981–2000 Baseline

Crop Type	Country	2050		2070	
		Worst case	Best case	Worst case	Best case
Sugarcane	Fiji	–9.05	–5.11	–20.55	–7.13
	Samoa	6.01	9.37	–2.30	5.69
Sweet potato	PNG	–59.16	–49.51	–68.37	–60.42
	Solomon Islands	–14.97	–12.22	–31.02	–22.52
Maize	Timor-Leste	–10.43	–6.07	–17.03	–13.51
	Vanuatu	–13.53	–8.03	n.d.	n.d.

n.d. = no data. Source: Boer and Rakhman (2011).

MODIS MCD12Q1 Land Cover 2008 L3 Global 500m (NASA 2009), and GlobCover 2009 (ESA 2010). The crop modeling, which incorporates carbon-dioxide fertilization, generated separate scenarios for low and high fertilizer rates. In addition, one scenario includes selection of the variety in the DSSAT database that performs best in 2050.

The Rosegrant et al. (2013) approach illustrates the divergence between the GCMs for key parameters affecting crop yield within a single emissions scenario. Depending on the model, changes in precipitation during the wettest months and during the driest months can vary greatly each year not only in magnitude but also can take an opposite direction for the same location. Even maximum temperature changes vary by more than 100% between the GCMs for the same scenario.

As a result of the variation between the climate parameters of the models, there is considerable variation also in the expected effects of climate change for the same crop and location, with some runs representing yield gains, and others representing yield losses (Table 5.2). This is exacerbated by the inclusion of optimal variety choice under one scenario. Cassava has the highest yield losses across the countries and across scenarios, while the overall balance of yield effects is most negative in the Solomon Islands. Unexpectedly, the worst-case yield effects for sweet potato in PNG are considerably smaller than in the Boer and Rakhman (2011) analysis, a result that may be due to the inclusion of carbon-dioxide fertilization.

The Rosegrant et al. (2013) approach is limited by the usage of monthly weather data interpolated via a stochastic weather generator; as such, it may not accurately represent the distribution of parameters within each month of cultivation. The effect of picking optimal model runs and parameters for varieties may cause some underestimation of yield losses, as farmers may select varieties and agricultural operations based on factors other than yield alone, and may have a constrained set of options as well. While a broader set of crops is included than in the Boer and Rakhman (2011) analysis, none of the top agricultural products of the region is included, thus limiting the representativeness of the analysis.

B. Evidence for Other Crops

To date, crops of primary importance to the Pacific have not yet been explicitly modeled under climate change. However, crop modeling and other evidence are available to suggest their susceptibility to climate change.

Coconut

Although there is little literature on the effects of climate change on coconut production in the Pacific region, Naresh Kumar and Aggarwal (2013) have modeled the effects of climate change on the tree crop in India. Averaging across climate change scenarios, nine out of 16 states in India are projected to have increases in coconut yield by 4% to 60%. These increases in coconut yield would offset the decrease projected for other states, resulting in

Table 5.2: Relative Changes in Crop Yields (%) under Climate Change in Year 2050 Relative to Year 2000 under the A1B Scenario

Crop	PNG		Solomon Islands		Fiji	
	Worst Case	Best Case	Worst Case	Best Case	Worst Case	Best Case
Cassava, rainfed	–30.8	17.7	–27.8	–17.9	–36.5	–8.8
Maize, irrigated	–3.2	4.0	–9.6	0.7	–6.1	2.3
Maize, rainfed	–3.8	9.0	–16.5	–0.3	–7.0	1.0
Rice, irrigated	–8.3	12.4	–7.6	10.8	–7.1	11.7
Rice, rainfed	–7.5	11.7	–16.2	5.9	–11.0	3.5
Sugarcane, rainfed	–3.6	3.4	–12.9	0.9	–8.3	2.8
Sweet potato, rainfed	–10.9	–1.2	–15.0	1.5	–13.4	2.0
Taro, rainfed	–13.0	3.6	–18.6	–4.7	–17.5	1.1

Source: Rosegrant et al. (2013).

a 1.9% to 6.8% increase on a national level under climate change. The increased coconut yield is attributed to the increased concentration of carbon dioxide, compensating for any negative effect of increase in temperature. However, the above results do not incorporate climate change effects on rainfall.

Oil Palm

Although the effects of climate change on oil palm yield have not been explicitly assessed for the Pacific, some evidence exists for a Southeast Asian environment at similar latitudes and with similar rainfall to many Pacific countries. Using a Ricardian econometric approach,[15] Zainal et al. (2012) estimated that every millimeter increase in rainfall and every degree Celsius increase in temperature due to climate change reduces the revenue per hectare of oil palm production by 0.1% and 1%, respectively. Based on the national communication submitted by Malaysia to the UNFCC, the yield of oil palm is expected to decrease by 30% with each 2°C increase in temperature and 10% decrease in annual rainfall due to climate change (Ministry of Natural Resources and Environment, Malaysia 2011).

Other perennials

Fruit trees and banana production, the leading agricultural products of the region, may be expected to be more sensitive to climate change than the crops modeled by Rosegrant et al. (2013) and Boer and Rakhman (2011). This is because production of perennial crops involves fewer opportunities for adjustments in management and varietal selection, given that the crop is established less frequently. These perennial crops are also all on the C3 photosynthetic pathway, which is more sensitive to changes in rainfall and temperature than the C4 photosynthetic pathway used by crops used in the modeling, such as maize and sugarcane.[16] Moreover, there are probably fewer opportunities for genetic improvement of these crops to embed tolerance to new climatic stresses. This is because breeding cycles have become longer due to longer reproductive cycles, and because breeding efforts are not as intensive as those for primary cereal crops.

C. Effects of Climate Change on Livestock Production

Livestock production can be affected by climate change in a number of ways. Heat can directly reduce animal activity, feeding, growth, and productivity, and it can also impede reproductive activity (Nardone et al. 2010). Increased water-deficit stress can diminish forage and feed productivity, thus reducing animal growth and milk and egg production. Changed climatic conditions can change vector- and disease-transmission and incidence, the effects of which may be exacerbated by direct heat stress. Extreme events and inundation attributable to climate change may reduce forage and feed production areas and increase mortality. While livestock are important in the Pacific, no explicit modeling has been performed to quantify the effect of climate change on their production in the region; this is an area that needs future research.

II. Marine and Coastal Impacts of Climate Change in the Pacific

A. Characteristics of the Marine Economy

The marine and coastal environment of the Pacific region provides a significant source of food and economic security for its coastal communities and population. The region's exclusive economic zone and territorial waters that dwarf available land resources serve as home to a diverse species of marine fisheries, mangroves, and coral reefs and they contain some of the highest marine biodiversity in the world.

The fisheries sector is an essential part of the economy of many small island countries of the Pacific. In Tuvalu, the FSM, Solomon Islands, Samoa, Palau, and Tonga, more than 5% of GDP is based on fisheries (Figure 5.2). Perhaps even more importantly, fisheries are essential to food security,

[15] A Ricardian method is based on the assumption of a direct cause and effect relationship between climate events and farm value. It assesses the contribution of environmental conditions to farm income. In doing so, it implicitly incorporates efficient adaptation by farmers to climate change.

[16] C3 plants are more efficient than C4 plants under cool and moist conditions. On the other hand, C4 plants can photosynthesize faster than C3 plants under high heat and light conditions and they have better water use efficiency.

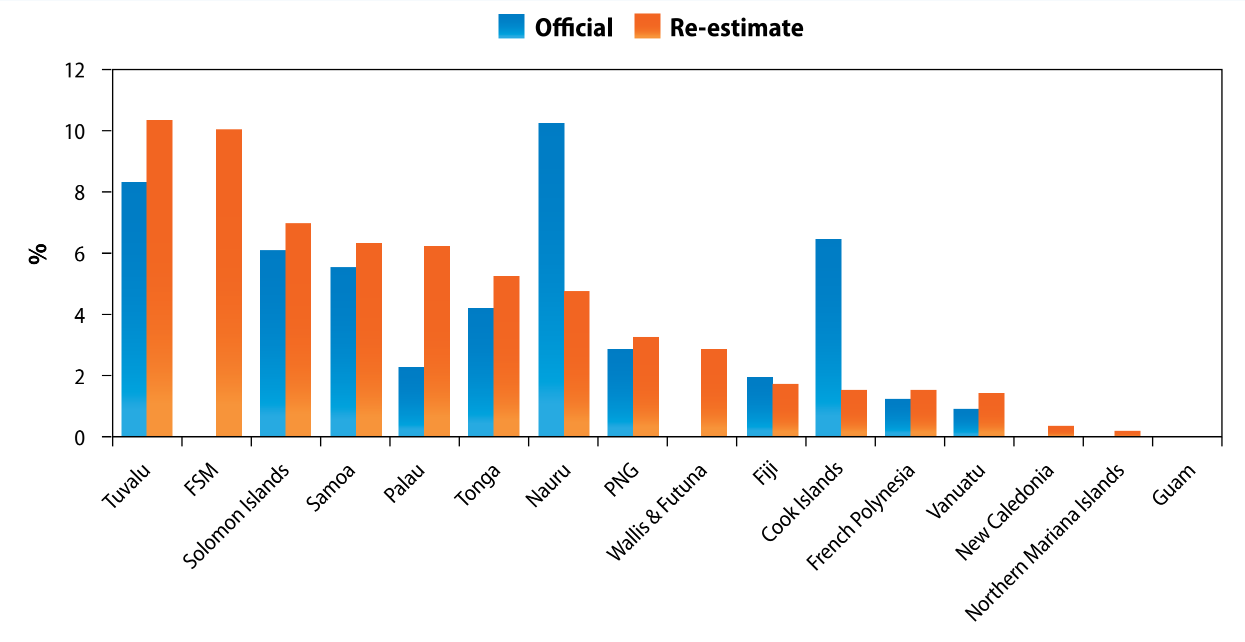
being the source of most of the animal protein consumed in many countries. Indeed, annual per capita fish consumption in many countries is in excess of 50 kilograms (kg) (Table 5.3).

Most income generated within the sector is derived from harvesting of ocean fish, particularly tuna. In addition, revenue collected from access fee payments generates a stable $80 million per year in government revenue. In the case of FSM, Tuvalu, Nauru and Kiribati, these fees provide an estimated 10% to 40% of annual government income (Bell et al. 2011).

B. Fisheries

Bell et al. (2011) have conducted in-depth analysis of the expected effects of climate change on the

Figure 5.2: Shares of Gross Domestic Product from Fisheries, 2007 (%)



Source: Gillett 2009.
Note that Gillet (2009) produced revised estimates of fisheries contributions to GDP that corrected for potential errors in national measurement approaches. While these provide a useful alternative measure of GDP contributions, they are not official statistics, and have not been endorsed by ADB.

Table 5.3: Per Capita Fish Consumption in Pacific Countries (kg/year/person)

Country	Range of Estimates
Cook Islands	47.0–71.0
FSM	72.0–114.0
Fiji	44.0–62.0
Kiribati	72.0–207.0
RMI	38.9–59.0
Nauru	46.7
Palau	84.0–135.0
PNG	18.2–24.9
Samoa	46.3–71.0
Solomon Islands	32.2–32.7
Tonga	25.2–30.0
Tuvalu	85.0–146.0
Vanuatu	15.9–25.7

Note: Estimates are on whole-fish equivalent basis.
Source: Gillett 2009.

Pacific's fisheries sector. In terms of biophysical effects, the analysis finds that rising sea-surface temperatures and more acidic oceans would have direct impacts on coral reefs and on the habitats and food webs that they provide for reef fish and invertebrates. Degraded coral reefs are likely to support different types of fish, thus lowering yields of some species. Reduced catches of reef-associated fish would widen the expected gap between the availability of fish and the protein needed for food security. Aside from these, the combination of increasing temperatures and sea-level rise are also expected to lead to changes in coastal circulation patterns, thereby affecting nutrient supply, exacerbating lagoon flushing and coastal erosion, and possibly increasing ocean acidity and coral bleaching (SPREP and PIFs 2007).

Changes in the distribution and abundance of marine fish catches

Changes in SST, combined with potential changes in wind, wave, and current patterns that result in water stratification, can lead to changes in nutrient availability to the photic zone, thus affecting the distribution of key fisheries species**.** Phytoplankton forms the base of the oceanic food web, and it determines the abundance and distribution of key fisheries species (Le Borgne et al. 2011; Polovina et al. 2011). Waves can change the geomorphology of islands and the coral reefs that surround them. This, in turn, can result in the loss and/or creation of habitat, which would also affect species distribution. Population connectivity in coral reefs and other ecosystems may also shift as winds, waves, current patterns, and temperature regimes are altered.

These observed patterns were confirmed by a vulnerability assessment study (Bell et al. 2011) using the SEAPODYM Model[17] that assesses effects of climate change on skipjack and bigeye tuna under the B1 and A2 emissions scenarios in 2035 and 2100. Results indicated that skipjack catches are likely to increase across the region in 2035, although the increases are expected to be greater for countries located in the eastern than those in the western Pacific. By 2100 under the B1 scenario, catches from the western Pacific are then projected to decrease and return to the average levels observed over the period 1980-2000 in the region. Fishery catches in Solomon Islands and PNG are expected to decrease by 5% and 10%, respectively. In contrast to this trend, fish catches in countries located in the eastern Pacific are projected to increase on average by more than 40%.

Under the A2 scenario in 2100, however, catches of skipjack tuna for the western Pacific are estimated to decline further by an average of more than 20% and by as much as 30% for PNG. Although catches in the eastern Pacific are still substantially greater than the 1980-2000 levels, they are expected to decrease relative to the projections for the B1 scenario. Across the entire region, total catch is projected to decrease by 7.5% under the A2 scenario by 2100. For bigeye tuna, small decreases in catch (usually less than 5%) are projected to occur by 2035. Catches are projected to decrease by 5% to 10% in most Pacific countries under the B1 scenario by 2100, and by 10% to 30% for many Pacific DMCs under the A2 scenario in 2100 (Table 5.4).

Other ranges of aquaculture commodities and production in the region that support livelihoods are also likely to be affected by climate change (SPC 2007). Some of these include pearl farming, which faces risks from acidification that may affect the quality and value of pearls produced in the future. Climate change may also affect the viability of farming seaweed (Kappahycus or "cottonii"), as conditions that cause coral bleaching are also not favorable to seaweed production. However, it is expected that the "winter syndrome" disease that causes problems for blue shrimp production in the Pacific may ease with the changing climate.

Impacts on freshwater fisheries

The vulnerability of freshwater and estuarine fish and invertebrates to climate change is expected to rise due to the combination of (1) direct effects of changes in physical and chemical quality of the water on the survival, growth, recruitment, and distribution of species, and (2) indirect effects caused by alterations to structure and complexity of the habitats that species depend on for food, shelter, and reproduction. Direct effects include

[17] SEAPODYM is a tool for investigating the spatial dynamics of tuna populations under the influence of fishing and environmental effects. The key features of the model, which incorporates an optimization approach, include: (i) analysis (forcing) of the effects of environmental variables, e.g., temperature, currents; (ii) primary production and dissolved oxygen concentration on tuna populations; (iii) prediction of the temporal and spatial distributions of functional groups of prey, (iv) prediction of the temporal and spatial distributions of age-structured predator (tuna) populations, (v) prediction of the total catch and the size frequency of catch by fleet; and (vi) parameter optimization based on fishing-data assimilation techniques.

Table 5.4: Percentage Changes in Catches of Skipjack and Bigeye Tuna Relative to 1980–2000 Period under the B1 and A2 Emissions Scenarios

Country	Skipjack tuna			Bigeye tuna		
	B1/A2 2035	B1 2100	A2 2100	B1/A2 2035	B1 2100	A2 2100
Cook Islands	40.4	50.2	47.4	–3.0	–7.8	–15.5
Fiji	25.8	24.0	33.1	0.8	0.7	–1.4
FSM	14.0	4.8	–15.8	–3.5	–11.5	–32.5
Kiribati	36.8	43.1	24.1	–0.7	–5.4	–16.6
RMI	24.0	24.2	9.8	–3.1	–9.6	–26.9
Nauru	25.1	19.7	–1.2	–1.4	–6.6	–19.5
Palau	10.2	1.7	–26.9	–3.9	–11.2	–45.2
PNG	3.1	–10.6	–30.2	–4.5	–13.0	–27.9
Samoa	44.0	49.2	54.9	1.4	1.4	–4.2
Solomon Islands	3.2	-5.5	–15.4	0.1	–2.9	–7.3
Tonga	47.0	50.2	58.5	–4.0	–5.1	–10.3
Tuvalu	36.8	40.9	25.0	2.9	2.2	–6.2
Vanuatu	18.4	15.1	26.1	–3.0	–6.1	–9.7

Source: Bell et al. (2011).

projected changes in water temperature, river flow rates, salinity, dissolved oxygen and turbidity (driven by alterations in surface-air temperatures, rainfall, and cyclone intensity), and increases in sea level (Bell et al. 2011). These changes are expected to affect the physiology and behavior of freshwater and estuarine fish and invertebrates as well as alter the normal cues for spawning and migration (indirect effects).

Most freshwater fish and invertebrates cannot instantly regulate their body temperature, and they often select thermal refuge within their habitat. Increases in water temperatures easily affect their metabolic rate, digestion, growth, and muscle performance. Freshwater fish and invertebrates found in shallow floodplain habitats in tropical regions often have higher temperature tolerances (above 35°C to 40°C). On the other hand, freshwater species living within the river channels are more likely to have lower temperature thresholds, and are adapted to water with a temperature lower than 35°C. Freshwater and estuarine fish and invertebrates in the tropical Pacific are quite sensitive, particularly when changes in water temperature happen during their early stages of development, as embryonic development and growth of larval fish are typically more rapid at higher temperatures. Fish in rivers and estuaries are particularly sensitive to changes in river flow and flow timing. This sensitivity is based on interactions between seasonal habitat availability, nutrient transport, algal production, food-web processes leading to increased recruitment, and cues for fish migration.

The frequency and intensity of El Niño events is also expected to become important in determining the long-term population size of tropical freshwater fish species. Changes to river ecosystems caused by ENSO and related weather cycles are likely to continue to cause variation in fishery yields from freshwater and estuarine habitats. Freshwater and estuarine fish are also expected to be affected by climate change effects on habitat quality, increased flushing, dissolved oxygen levels, and salinity intrusion.

Production of freshwater fish and invertebrates in these selected Pacific DMCs may increase by up to 2.5% in 2035, by 2.5% to 7.5% under B1 in 2100, and by 7.5% under A2 in 2100 (Bell et al. 2011). These estimates do not take into account changes in fishing effort or the effects of catchment alteration. The uncertainty associated with these estimates is reflected in the range of expected changes in fish production, which are based largely on expected variation in habitat availability.

Box 5.1: Potential Effects of Projected Changes to Surface Tuna Fishery on Economic Development and Government Revenue

Bell et al. (2011) projected the effects of changes to surface fisheries on the economies of selected Pacific countries under the B1 and A2 scenarios in 2035, B1 in 2100, and A2 in 2100. The range was based on the variation in estimates of the value of tuna production and government revenue derived from the surface tuna fishery between 1999 and 2008. The estimates were also based on the following assumptions:

- Projected catches of skipjack tuna are a good indicator of the effects of changes to the surface fishery on national economies because landings of skipjack dominate this fishery;
- Variations in catch will have similar impacts both on GDP and on government revenues. Thus, if the contribution of the surface fishery is estimated to be 5% of GDP, and catch is projected to rise by 10%, then the increased contribution to GDP due to the greater catch is estimated to be 0.5% of GDP;
- Tuna prices, GDP, levels of taxation, and the value-added component of purse-seine and pole-and-line fishing operations remain constant relative to 1999–2008 levels. These assumptions are common in other future economic vulnerability analyses;
- The balance between catches by locally-based fleets (which contribute to GDP); and
- Constant fishing effort.

The projected increases in catches of skipjack tuna by 2035 show that landings are expected to rise by approximately 20% across the fishery, driven by strong increases in catch (> 35%) in the eastern part of the region and more modest increases in catch (10%) in the west. The expected improvements in catch lead to projected increases in GDP and government revenue by 2035, particularly for those Pacific DMCs in the east. The most significant projected increases to GDP associated with the projected changes in catch are for RMI (2% to 6%). The highest expected increases in government revenue are for Kiribati (11% to 18%), Tuvalu (4% to 9%), and Nauru (2% to 6%).

Under the B1 scenario in 2100, the catch of skipjack tuna is projected to rise by 12% overall, driven by expected increases of > 40% in catch in the eastern region of the fishery, with a marginal decline in projected catches in the western region. Projected decreases in catch of 11% in PNG and 5% in Solomon Islands by 2100 under the B1 scenario are expected to lead to declines in GDP and government revenues. However, due to the relatively low importance of surface fishery to the larger economies, GDP is estimated to decline by only 0.1% to 0.4% in both countries. Government revenues are also expected to fall by only 0.1% in PNG and by 0.3% in Solomon Islands.

By 2100 under the A2 scenario, catches of skipjack tuna are projected to fall for fishery as a whole by around 7% because the modest projected increases in the east of the region (27%) would be more than offset by the expected 21% decline in the larger component of the fishery in the west. The projected 30% decline in catches of skipjack tuna in the EEZ of PNG is particularly significant, although it is estimated to result in a reduction of only up to 1.2% in GDP and 0.2% in government revenue due to the large size of the economy in PNG. The projected declines of about 15% in catches from Solomon Islands and FSM are also expected to cause reductions of about 0.8% to 1% in GDP, and 1% to 2% in government revenue for both countries. The catch in Nauru, and consequentially government revenue, is expected to fall only marginally. RMI, Kiribati, and Tuvalu are projected to continue to receive increased economic benefits under the A2 scenario in 2100, albeit at lower levels than for B1 and A2 in 2035 or under the B1 scenario in 2100.

Source: Bell et al. 2011.

III. Tourism

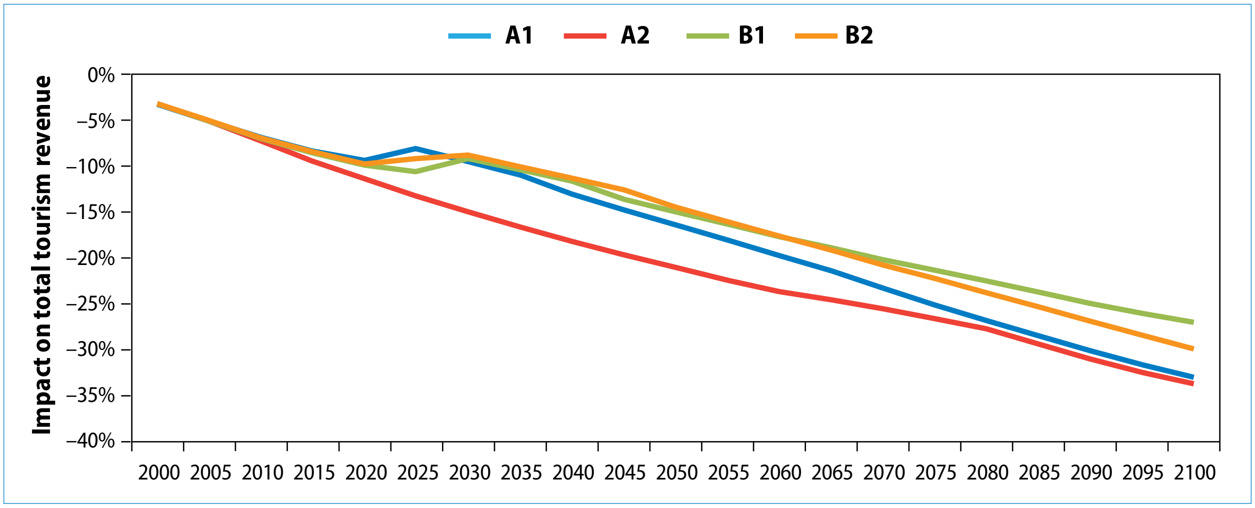
As indicated earlier in Chapter 2, tourism is a mainstay of the economy of a number of smaller countries in the Pacific. In the Cook Islands and Palau in particular, it accounts for a majority of GDP, while it is 20% or more of GDP in Fiji, Samoa, and Vanuatu (Table 2.2).

Climate change can affect the tourism sector by changing the attractiveness of the climate of tourism destinations, by reducing the value of attractions at destinations, and by altering the relative climate of the home countries of tourists. As noted earlier, climate change is also expected to damage corals, which can both reduce the attraction of the region for diving and snorkeling and cause the loss of attractive beach area.

As part of this study, ADB commissioned a study (Tol 2011) to apply the HTM to quantify possible changes in tourism flows as a result of climate change in the Pacific. At the core of the model is a matrix of tourism flows from one country to the next, based on scenarios of population, income, and climate change. Data on international arrivals and departures for 1995 are taken from the World Resources Databases (http://earthtrends.wri.org), while domestic tourist numbers are taken from the Euromonitor (2002) database (see Bigano et al. 2007). The number of holidays is a function of per capita income, with saturation because of limits on leisure time. Shares of international holidays are also functions of per capita income, with similar saturation patterns. These factors, plus population growth, drive the baseline projection of domestic and international tourism (Mayor and Tol 2010). The modeling assumption is that tourists prefer to spend their holidays in a Mediterranean summer climate. Warmer and colder places are less attractive. Tourists who live in a country with a climate that is close to the ideal are less likely to travel abroad. Tourists who travel are more likely to go to a country with the ideal climate. Tourists from warmer countries have more pronounced climatic preferences, while tourists from colder climates have more diffuse tastes (Bigano et al. 2007). The dependent variables are average lengths of stay and expenditures.

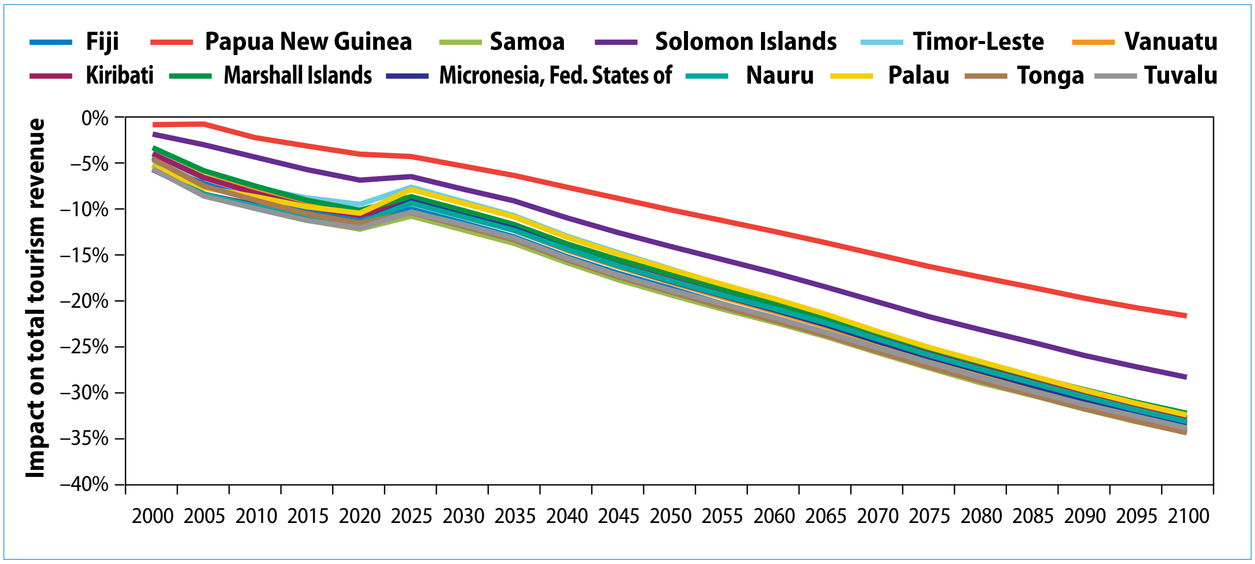
As the world warms up, the Pacific region as a whole becomes a lesser tourism attraction and its total tourism revenues are expected to fall. The situation would steadily worsen over the century, except for a brief period around 2025 when increases in international tourists from PRC would outweigh decreases of tourism from other regions. By the end of the century, tourist numbers are expected to fall by about one-third. Under all climate scenarios, the impact of climate change would be to reduce tourism revenues by 27% to 34% for the Pacific region as a whole (Figure 5.3). Declines in tourism

Figure 5.3: Impact of Climate Change on Total Regional Tourism Revenue under various Emissions Scenarios



Source: ADB study team.

Figure 5.4: Impact of Climate Change on National Tourism Revenue under the A1 Scenario



Source: ADB study team.

revenues are projected to be less severe in PNG compared to other countries (Figure 5.4).

The analysis offers a useful illustrative example of potential tourism effects. When the effects of coastal inundation, coral bleaching, fisheries declines, and increased health risks are combined, the effects on tourism may be larger than those due to temperature alone.

IV. Decline in Coral Reefs

Coral reefs serve as habitat and protection to many coastal fish species. In addition, they are also one of the central attractions of the region's tourism industry, both directly for diving and snorkeling, and indirectly for its vital role in maintaining beach and coastal land levels against the eroding forces of storms and rising seas. The drawback, however, is that coral reefs are very vulnerable to climate change.

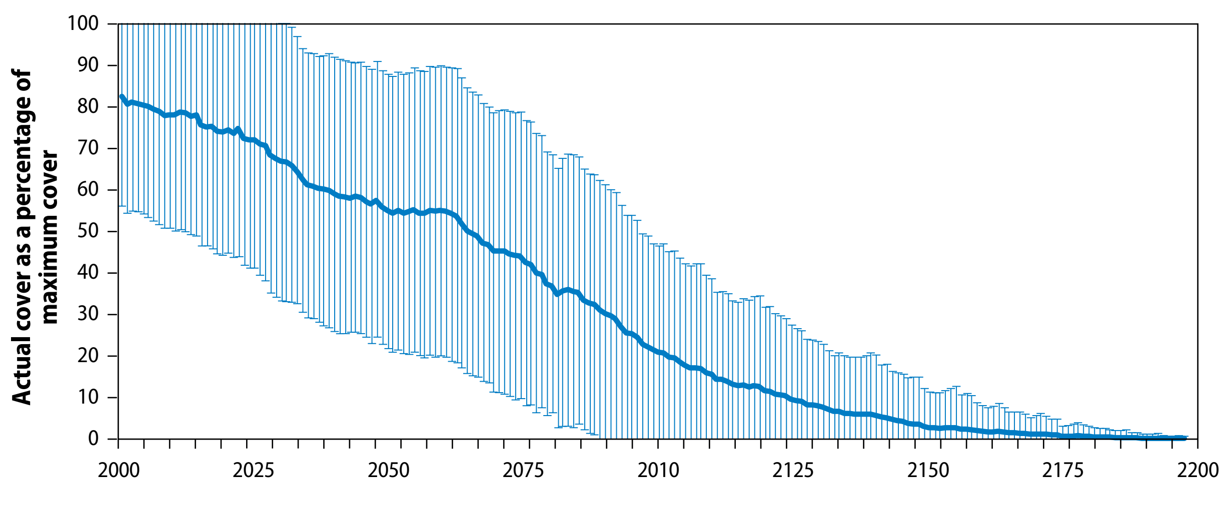
Coral bleaching occurs when water temperatures rise 1.8°C to 3.6°C above the warmest normal summer temperatures, which are associated with strong El Niño events (Hoegh-Guldberg 1999). Ocean warming induces coral stress, causing the corals to expel their crucial, colorful symbiotic algae and to turn white. Prolonged and intense coral bleaching is often followed by coral death due to starvation, since the by-product of algal photosynthesis is a primary food source of the coral (Donner 2011). Adding to the stress of high temperatures is the increasing acidification of the ocean owing to rising levels of carbon dioxide in the air that is absorbed by seawater. One of the impacts of ocean acidification is that less carbonate is available in the form necessary for coral reefs to build their calcium carbonate skeletons. The skeletons that these small coral polyps build are a fundamental building block of coral-reef ecosystems.

The Pacific region has a very large coral reef cover, about 18% of the world's total, and three of its countries, PNG, Fiji, and RMI are among the top ten richest in reef resources in the world (Spalding et al. 2001). Mass coral bleaching due to thermal stress has already occurred in the Pacific region and is expected to recur with the foreseen increases in future sea temperatures. Figure 5.5 presents a projection of coral cover in the Pacific under climate change using an extension model of FUND3.6 (Tol 2011).

The estimate of present coral area in the Pacific in 2000 is around 80% of what would have been in the absence of thermal stress (in the pre-industrial era). The analysis indicates that the Pacific would experience an increase in thermal stress that would likely result in a significant decline in coral reef cover, from 88% in the base year (1995) to 55% in 2050 and 20% in 2100. Coral-reef cover is further projected to be less than 1% by 2200. The critical bleach probability of 23% per year will be exceeded by 2140. Beyond this point, the equilibrium coral cover will be zero (Box 5.2).

These estimates are in line with previous literature. Based on the rate of coral loss reported over the past 20 years and the projected effects

Figure 5.5: Projection of Coral Cover in the Pacific with Climate Change (FUND3.6)



Source: Tol 2011.

Box 5.2: Pacific Coral Reefs and Climate Change

Hoegh-Guldberg et al. (2011) combined biological models of the marine environment with the Coupled Model Intercomparison Project Phase 3 (CMIP3), a multi-model data set used in IPCC's AR4 to provide projections on the physical climate. Model parameters used on the CMIP3 were based on two emissions trajectories: low (B1) and high (A2) emissions illustrating both near-term (2035) and long-term (2100) projections. Results show that substantial changes in ocean circulation and temperature structure are expected to occur and are likely to impact biological productivity. Sea-surface temperature is expected to increase within the range of 0.5°C to 1.0°C. Changes to the atmosphere and tropical Pacific Ocean under the B1 and A2 scenarios are expected to be largely indistinguishable in 2035, diverging only later this century. By 2100 under the B1 and A2 emissions scenarios, SST is expected to be 1.0°C to 1.5°C and 2.5°C to 3.0°C warmer relative to 1980–1999. Increases in atmospheric CO2 are projected to lead to substantial additional acidification of the ocean, reduction of the pH of the ocean, and decreased levels of aragonite, thus jeopardizing the growth of corals. More specifically, the modeling finds the following outcomes as a result of expected temperature changes and acidification:

The next two to three decades: Coral reefs in 2035 (B1 and A2)

Reef-building corals will decrease by approximately 25% to 65% by 2035, in a manner consistent with the annual 1% to 2% decline observed in recent years. This will reduce the structural complexity of coral reefs and their ability to provide habitat for fish and invertebrates. Management actions are likely to reduce the magnitude of the loss, although the benefits of management are not expected to differ between the B1 and A2 scenarios in 2035. Coral mortality is usually followed by algal colonization, so that coral reefs are also likely to experience a 130% to 200% increase in benthic algal cover, including algal turfs and non-calcareous macroalgae, depending on the strength of management.

Coral reefs in 2100 (B1)

At the end of this century, under the B1 scenario, coral reefs in the tropical Pacific are likely to have reduced coral cover and to be less diverse. Management of these reef systems would have a significant effect, and strong intervention should lead to healthier reefs under the B1 scenario. However, calcification rates are not expected to keep pace with physical and biological erosion, thus leading to the collapse of many reef frameworks and the loss of habitat. As a result, the production of coastal fisheries is expected to decrease by 10% to 20%. These changes, together with the expected rise in sea level, would mean that the coastal protection offered by coral reefs would no longer be provided. This could have significant consequences for coastal urban areas and infrastructure, especially in those Pacific countries comprised by low-lying atolls.

Coral reefs in 2100 (A2)

The changes projected under the A2 scenario are expected to cause many coral species to become extinct or extremely rare. By 2100, coral reefs are likely to be dominated by algal turfs and organisms other than corals (e.g., cyanobacteria) and the few corals present (< 2% of total cover) are likely to be very robust organisms suited to extremes (extremophiles). Net reef accretion is projected to be non-existent and reef structures are expected to break down under physical and biological erosion. Demersal fish populations are also likely to be fundamentally different, with their productivity projected to be 20% to 50% lower than in 2010. No amount of management action to reduce local threats is expected to have any effect on reef health.

Beyond 2100: Reef recovery versus complete collapse

Strong action on greenhouse-gas emissions and vigorous attempts to reduce the effects of local threats such as declining water quality from pollution, overfishing, destructive fishing practices, and mining could help coral reefs in the B1 scenario to redistribute and regenerate around the Pacific as conditions stabilize. Over time, populations of corals adapted to warm conditions at the equator are expected to expand slightly towards higher latitudes. However, these coral populations would struggle to maintain structurally complex carbonate-reef systems because of the low concentrations of carbonate ions in the oceans of the next century and beyond. Nevertheless, these populations should be able to build coral reefs with a degree of diversity, similar perhaps to those currently found in the eastern Pacific. Although these reefs are expected to have low biodiversity and no net accretion of carbonate structure, they should continue to support substantial fish populations and fisheries. In contrast, the A2 scenario, with its rapid and continuing changes to SST, ocean pH, carbonate ions, and sea level, is expected to result in environmental conditions that continue to outpace ecological processes for centuries to come. This would lead to low-productivity coral reefs, with little value for the people of the Pacific.

of more frequent coral bleaching and ocean acidification, average coral cover throughout the Pacific is expected to decline to 15% by 2035 (Pratchett et al. 2011). Burke et al. (2011) find that by 2050, many of the reefs in the Pacific would bleach every year.

The loss of coral reefs would have implications for an array of goods and services of importance to the Pacific. These include recreational opportunities for diving, snorkeling and viewing, coastal protection, habitat and nursery functions for commercial and recreational fisheries, and coral mining. Coral bleaching and decline as a result of climate change would compound effects on tourism as quantified by Tol (2011) based on climatic favorability, as well as on certain declines of oceanic fisheries catches as identified by Bell et al. (2011). In addition, and important in its own right, the decline of coral reefs would mean the loss of areas of great importance to the sustenance of marine biodiversity.

V. Health

Many countries of the Pacific region currently experience poor health status that may be exacerbated by climate change. Life expectancy at birth ranges from a low 55 years in Nauru to 73 in Samoa in 2005; children under 5 mortality rates range from 13 per 1,000 live births in Samoa to 74 in PNG; and access to improved sanitation range from 25% in the FSM to 100% in Samoa (Table 5.5). Moreover, the incidence of communicable and non-communicable diseases is currently rising (Hanna et al. 2011).

A. Climate change Effects on Health

Climate change would have both direct and indirect effects on health in the region (Figure 5.6).

Direct effects include effects from heat stress and water shortages and from water-borne, food-borne, and vector-borne diseases. Indirect pathways include effects of increased climate variability on infrastructure and economic development, as well as of climate change effects on agriculture and food security.

Increases in temperature associated with climate change would drive higher relative humidity values. This would push ambient Wet Bulb Globe Temperatures, or "experienced heat," from a central value of around 31°C to above 35°C (Hanna et al. 2011). Values above 35°C are a point at which limited physical exercise would be sufficient to cause dangerous heat stress and associated cardiovascular and respiratory problems. As a result, labor productivity would decline and increased injuries would occur.

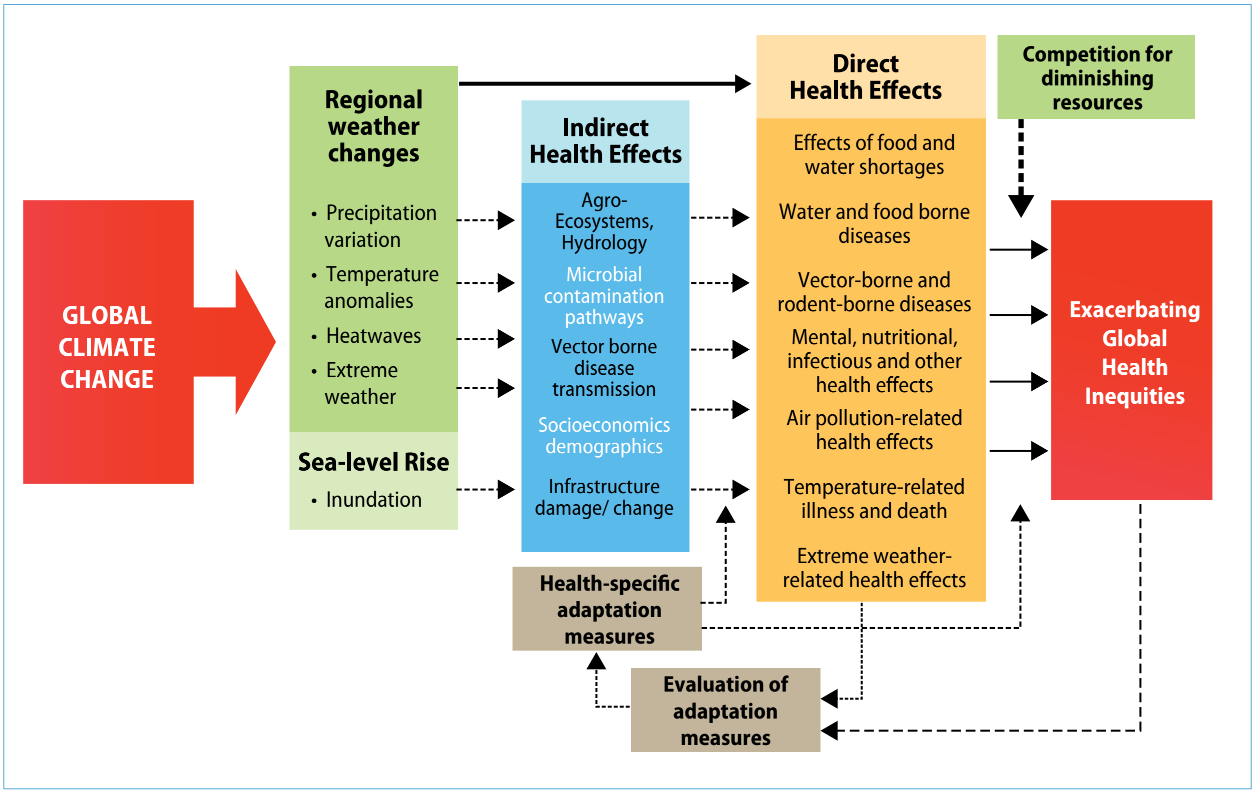
As a result of more intense rains, increased flood events are expected under climate change in the region. These flood events would not only

Table 5.5: Selected Summary Statistics Regarding Health in Pacific Countries

Pacific DMCs	Life expectancy at birth (years)	Under-five mortality rate (per 1000 livebirths)	Population with access to improved sanitation (%)
Fiji	70	24	71
Kiribati	67	48	33
FSM	69	39	25
Nauru	55	38	50
Palau	69	26	83
PNG	61	74	45
Samoa	73	13	100
Solomon Islands	66	37	32
Tuvalu	64	36	84
Vanuatu	69	31	52

Source: Hanna et al. 2011.

Figure 5.6: Direct and Indirect Health Effects of Climate Change



Source: Hanna et al. 2011.

create injuries and direct contaminant exposure but lead to contamination of freshwater resources with pathogens and other substances. They also can increase habitat favorability for disease vectors and lead to population displacement, which in turn would facilitate disease transmission (McMichael et al. 2003).

The ecology, habitats, and reproduction of disease vectors are affected by climate, and they generally increase under warmer temperatures with climate change. Similarly, transmission of diseases from livestock to humans is anticipated to grow under warmer temperatures (Fust et al. 2009). Increases in temperature and humidity would also create more favorable conditions for food-borne disease as well as for diseases transmitted via unsanitary conditions (Tirado et al. 2010).

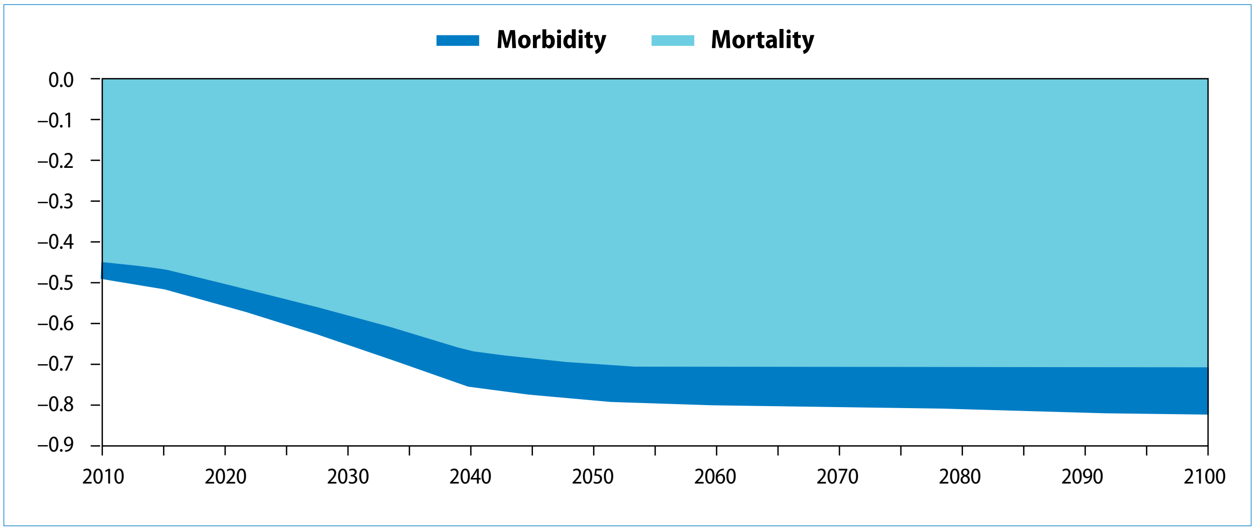
Although no quantitative analysis has yet been performed for the region, it is likely that increases in disease burden attributable to climate change would lead to lower labor productivity and economic growth as well as increased healthcare costs. In addition, increases in childhood disease risk would lead to permanent disabilities, with attendant costs to economic growth in individual sectors and personal well-being. This, in turn, would act as a multiplier on impacts in other sectors.

B. Estimated Impacts of Climate Change on Health in the Pacific

Human health costs are valued in terms of foregone income and additional expenditure for treatment of illnesses. Based on an ADB-commissioned research using the model developed by Tol (2002a, 2002b), mortality and morbidity costs together are expected to reach at 0.8% of GDP by 2100 under the A1B scenario (Figure 5.7). Most of the estimated health costs would arise from respiratory disorders, followed by malaria and deaths from tropical storms (Figure 5.8). By 2100, approximately 80% of total mortality cost would be caused by respiratory disorders due to climate change, and 14% by vector-borne diseases, particularly malaria.

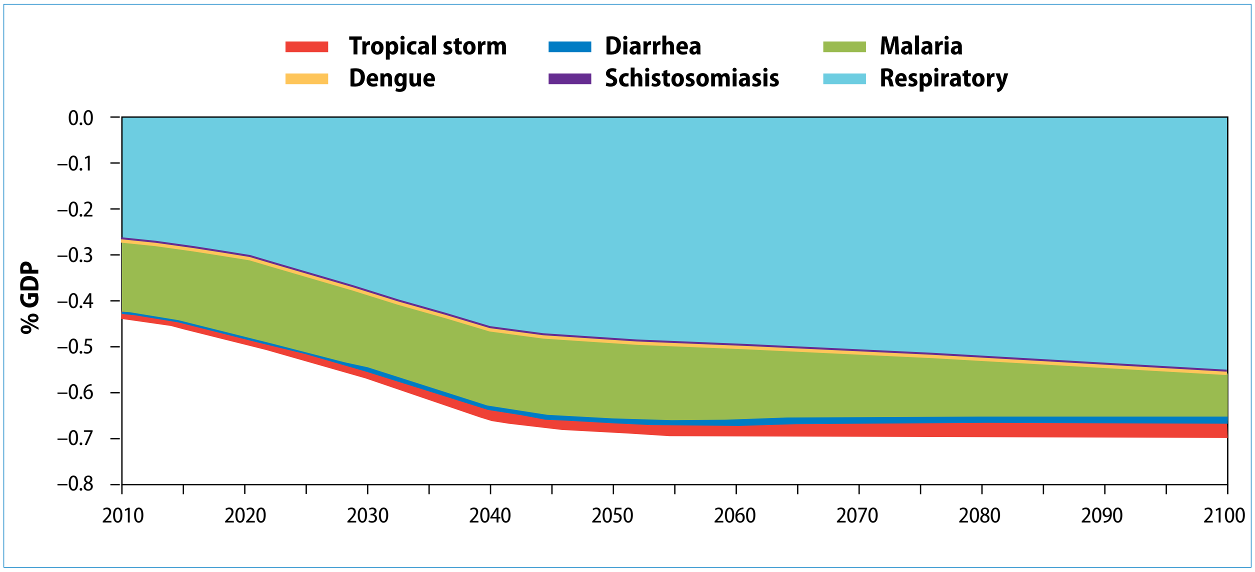
The next chapter presents further aggregate estimates of the economic costs of climate change in the Pacific region.

Figure 5.7: Health Cost of Climate Change in the Pacific under A1B Scenario (as a % of projected GDP)



Source: ADB study team.

Figure 5.8: Contributors to Mortality Cost due to Climate Change in the Pacific



Source: ADB study team.

References

Ainsworth, E.A. and S.P. Long. 2005. What have we learned from 15 years of free-air CO2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO2. *New Phytologist*. 165. 351–372.

Barnett, J. and J. Campbell. 2010. *Climate Change and Small Island States: Power, Knowledge and the South Pacific*. Earthscan LLC. Washington, D.C. US.

Bartholome, E. and A. S. Belward. 2005. GLC2000: A new approach to global land cover mapping from Earth observation data. *International Journal of Remote Sensing*. 26.1959–1977.

Batjes, N. et al. 2009. *Harmonized World Soil Database*. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Bell J. D. et al. 2011. *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Secretariat of the Pacific Community, Noumea, New Caledonia.

Bigano, A. et al. 2007. The impact of climate change on domestic and international tourism: A simulation study. *Integrated Assessment Journal*. 7. 25–49.

Boer, I.R. and A. Rakhman. 2011. Adaptation and impact of current and future climate variability on agriculture sector. In *Final Report: The Assessment of Economics of Climate Change in the Pacific*. Draft report submitted to ADB by CCROM, Bogor, Indonesia.

Brown, R.A. and N.J. Rosenberg. 1999. Climate change impacts on the potential productivity of corn and winter wheat in their primary United States growing regions. *Climatic Change*. 41. 73–107.

Burke, L. et al. 2011. *Reefs at Risk*. World Resources Institute. Washington, D.C. US.

Challinor, A.J. et al. 2004. Design and optimisation of a large-area process-based model for annual crops. *Agricultural and Forest Meteorology*. 124. 99–120.

Donner, S.D. 2011. An evaluation of the effects of recent temperature variability in the prediction of coral bleaching events. *Ecological Application.* 21. 1718–1730.

European Space Agency (ESA). 2010. GlobCover 2009 land cover map, v2.3. Available: http://ionia1.esrin.esa.int/

Fust, W. et al. 2009. *The Anatomy of a Silent Crisis. Human Impact Report: Climate Change*. Geneva, Switzerland: Global Humanitarian Forum.

Gillett, R. 2009. *Fisheries in the Economies of the Pacific Island Countries and Territories*. Asian Development Bank. Manila.

Hanna, E.G. et al. 2011. *Overview of Climate Change Impacts on Human Health in the Pacific Region*. National Centre for Epidemiology & Population Health College of Medicine, Biology & Environment Australian National University, Canberra, Australia.

Hoegh-Guldberg, O. 1999. *Climate Change, Coral Bleaching and the Future of the World's Coral Reefs*. The Coral Reef Research Institute, University of Sydney.

Hoegh-Guldberg, O. et al. 2011. Vulnerability of coral reefs in the tropical Pacific to climate change. In: J.D. Bell et al. (eds). *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Secretariat of the Pacific Community, Noumea, New Caledonia.

Intergovernmental Panel on Climate Change (IPCC). 2007: *Climate Change 2007: The Physical Science Basis. Summary for Policymakers*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Secretariat. Switzerland.

Jones, J.W. et al. 2009. *Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI*. International Livestock Research Institute, Nairobi, Kenya.

Le Borgne, R. et al. 2011. Vulnerability of open ocean food webs in the tropical Pacific to climate change. In: J.D. Bell (ed). *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Secretariat of the Pacific Community, Noumea, New Caledonia, pp. 189–249.

Mayor, K. and R.S.J. Tol. 2010. Scenarios of carbon dioxide emissions from aviation, *Global Environmental Change*. 20. 65–73.

Meza, F. J. et al. 2008. Climate change impacts on irrigated maize in Mediterranean climates: Evaluation of double cropping as an emerging adaptation alternative. *Agricultural Systems*. 98. 21–30.

Ministry of Natural Resources and Environment, Malaysia. 2011. *Malaysia: Second National Communications submitted to the United Nations Framework Convention on Climate Change. Kuala Lumpur*, Malaysia. Ministry of Natural Resources and Environment.

McMichael, A.J. et al. 2003. *Climate Change and Human Health Risks and Responses*. Geneva. World Health Organization, World Meteorology Organization, UNEP.

Nardone, A. et al. 2010. Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science*. 130. 57–69.

Naresh Kumar, S., and P.K. Aggarwal. 2013. Climate change and coconut plantations in India: Impacts and potential adaptation gains. *Agricultural Systems*. 117. 45–54.

NASA Land Processes Distributed Active Archive Center (LP DAAC). 2009. *MODIS MCD12Q1 Land Cover 2008 L3 Global 500m SIN Grid*. USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota.

Polovina, J.J. et al. 2011. Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. *ICES Journal of Marine Science*. doi:10.1093/icesjms/fsq19.

Pratchett, M.S. et al. 2011. Changes in the biodiversity and functioning of reef fish assemblages following coral bleaching and coral loss. *Diversity*. 3. 424–452.

Rosegrant, M.W. et al. 2013. *Climate Change, Food Security and Sound Economic Livelihood in Pacific Islands*. Draft report submitted to the Asian Development Bank. IFPRI, Washington, DC, US.

Sivakumar, M.V.K. 2005. Impacts of natural disasters in agriculture, rangeland and forestry: an overview. In M.V. K. Sivakumar et al. (eds) *Natural Disasters and Extreme Events in Agriculture: Impacts and Mitigation*. Springer-Verlag Berlin Heidelberg.

Secretariat of the Pacific Community (SPC). 2007. *The Future of Pacific Fisheries – Planning and Managing for Economic Growth, Food Security and Sustainable Livelihoods*. 5th Conference of the Pacific Community, Apia, Samoa, 12–13 November 2007.

Secretariat of the Pacific Regional Environment Programme (SPREP Pacific Islands). 2007. *Regional Marine Species Programme* 2008-2012. Apia, Samoa, SPREP: 48.

Spalding, M.D. et al. 2001. *World Atlas of Coral Reefs*. Berkeley, University of California Press.

Terry, J.P. and T.F.M. Chui. 2012. Evaluating the fate of freshwater lenses on atoll islands after eustatic sea-level rise and cyclone-driven inundation: A modeling approach. *Global and Planetary Change*. 88–89: 76–84

Tirado, M.C. et al. 2010. Climate change and food safety: A review. *Food Research International*. 43. 21.

Tol, R.S.J. 2002a. Estimates of the damage costs of climate change - Part I: Benchmark estimates. *Environmental and Resource Economics*. 21. 47–73.

______. 2002b. Estimates of the damage costs of climate change - Part II: Dynamic estimates. *Environmental and Resource Economics*. 21. 135–160.

______. 2011. *The Economic Impact of Climate Change on Pacific Island Nations*. Draft report submitted to the Asian Development Bank.

Wairiu, M. et al. 2012. Climate change implications for crop production in Pacific islands region. In A. Aladjadjiyan (ed). *Food Production - Approaches, Challenges and Tasks*. InTech.

Zainal, Z. et al. 2012. Economic impact of climate change on the Malaysian palm oil production. *Trends in Applied Sciences Research.* 7. 872–880.

Zhao, Y. et al. 2005. Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics. In: J. Salinger et al. (eds.) *Increasing Climate Variability and Change: Reducing the Vulnerability of Agriculture and Forestry*. Springer. The Netherlands.

Chapter 6

ECONOMIC IMPLICATIONS OF CLIMATE CHANGE IN THE PACIFIC

Understanding the dynamic linkages between climate change and socioeconomic characteristics is fundamental to the design of adaptation policies and strategies for supporting sustainable economic development and growth in the Pacific DMCs. IAMs provide a useful tool to combine information and knowledge from a wide range of disciplines and they are able to produce results consistent across various impact sectors (Box 6.1). Their primary goal is to inform policy decisions with insights that could not be gained from isolated studies of various aspects of climate change and its impacts. Using a consistent and coherent framework, IAMs help investigate future scenarios for different assumed emissions paths, allow the estimation of the cost of carbon to society, and enable the determination of the benefits and costs of climate policy and adaptation pathways. As indicated in Chapter 3, this study employs two main IAMs, namely PAGE09 and FUND3.6, to estimate the economic impact of climate change on the Pacific region.

To provide some consistency in the scenarios and parameters based on climate information gathered through GCMs and RegCM3, both FUND3.6 and PAGE09 have been calibrated to work with the same degrees of temperature rise as the GCMs and RegCM3 results for the Pacific region. Similarly, to the extent possible, relevant parameters of FUND3.6 and PAGE09 have been calibrated to project the physical impacts that are consistent with the results suggested by the sector models in terms of sea-level rise, coastal impact (land loss), and yield loss. However, the default values of FUND3.6 and PAGE09 were for all other impact sectors beyond the scope of sector assessments in the study. Also, because a detailed assessment of climate information and sector impact is available for only six Pacific DMCs, the results for the rest of the region had to rely on the default values.

Employing these models allows for: (i) analyzing long-term economic impacts of climate change; and (ii) estimating the magnitude of funding required in the Pacific to respond to climate change. However, the estimates are sensitive to a number of assumptions and uncertainties in the modeling of climate and socioeconomic systems and their interactions. For example, the total economic cost of climate change depends on the coverage of sectors and impacts in the models. Both models include key sectors (agriculture, water, coastal, energy, human health, and ecosystems), but not all sectors. Furthermore, estimates are contingent upon how future scenarios unfold, what time time-horizon is envisaged, and how societies value their futures and future generations, among other factors. Therefore, the results should always be interpreted within the model confinements and scenarios, and they should be taken as only indicative rather than predictive.

Box 6.1: On the Use of IAMs and Estimating the Economic Impacts of Climate Change

IAMs offer mechanisms for integrating a climate model with an economic model to determine how changes in climate are likely to impact production, consumption, and other economic variables of interest. The climate model presents scenarios of greenhouse-gas emissions and their estimated impact on temperature, while the economic model describes how changes in climate are likely to impact the various economic variables. An IAM-based economic analysis of climate change impacts typically has six elements that can either be determined by the model itself or adapted from other models for use as inputs into the IAMs.

These six elements—three for the climate model and also three for the economic model—are described below.

Climate Model

1. Projections of future emissions of greenhouse gases under various emissions scenarios, typically under a "business as usual" scenario and then under an abatement scenario. This element requires projections of population, economic, and technological parameters; for example, the amount of greenhouse-gas emissions per dollar of GDP will depend on (i) assumptions pertaining to the sectoral composition of future economies, and (ii) assumptions pertaining to future technological development.
2. Projections of future atmospheric concentrations of greenhouse gases based on past, current, and projected future emissions as described in the first element above.
3. Projections of global or regional changes in climate variables, typically including temperature and rainfall (average, extreme, and variability), hurricane frequency, and rises in sea level. This element is projected based on changes in future atmospheric concentrations of greenhouse gases as described in the second element above.

Economic Model

4. Projections of the economic impacts of higher temperatures (or other climate variables of interest) as projected by the climate model. This element estimates economic impacts at the global, regional, or national level, and are generally expressed in terms of lost GDP. These impacts may also be estimated by economic sectors of interest.
5. Estimates of the cost of abating greenhouse-gas emissions by various targeted amounts.
6. Assumptions about society's utility function and the discount rate.

Since each IAM makes its own interpretation of the standard climate "storyline" scenarios, its definition for a particular scenario, while qualitatively harmonized, may be quantitatively different with respect to exact greenhouse-gas atmospheric concentrations and to the evolution of social and economic change among IAMs.

IAMs can be classified into two broad groups, namely: (i) the fully integrated models that include, among others, the Dynamic Integrated Model of Climate and the Economy (DICE), ENTICE, RICE, FEEM-RICE, World Induced Technical Change Hybrid (WITCH), MERGE, and the Integrated Climate Assessment Model (ICAM); and (ii) the non-CGE models that include FUND3.6 and PAGE09.

Fully integrated models, including both of the economic and climate modules described above, allow for the modeling of interactions between economic and climate systems. These models have been used extensively for analyses of environmental policy, such as determining the effects of carbon taxes and other regulatory mechanisms in the economy on the targeted emissions reductions. Non-CGE models, which are regarded as "policy evaluation models," make user-defined assumptions about a course of future policy, then calculate the implications of the specified policy variables of interest (e.g., temperature change, ecosystem and agricultural yield changes, sea-level rise). In general, non-CGE models include a climate module and a damage module; economic projections are exogenous to or not taken into account in the model.

There are a number of limitations to IAMs. Most of the functions used in modeling relationships between exogenous and endogenous variables are based on simple functions—functions derived from reduced–form equations that are identified during econometric analyses or review of scientific literature. These functions are dependent on the availability of data and on their ability to include all relevant independent variables; these variables, however, may prove inadequate in the case of complex modeled relationships. Typically, the functional forms embedded in IAMs are monotonic and do not reflect the discontinuities that may be present in true relationships related to climate; moreover, they often reflect relationships for which evidence is mixed and understanding is still evolving, as in carbon-dioxide fertilization in agriculture. Often not included in IAMs are interactions among responses and feedback loops. For example, when growth is taken as exogenous in non-CGE models, the consequences of climate change are not incorporated in the underlying projections of economic development; this causes the projections of growth to overwhelm the identified damage costs, resulting in bias towards underestimation of climate impacts.

IAMs cannot directly incorporate exogenous climate data or results on sectoral impacts, as these are endogenous to the models. For this reason, in Chapter 6 of this study, the climate work presented and the sectoral impact estimates are not used directly in the integrated assessment modeling. However, using the exogenous climate data, IAMs can parameterize the functional relationships between exogenous and endogenous variables to tailor responses to the individualities of particular locations. In the particular case of this study, the sectoral and sea-level rise results were used as a point of reference so as to parameterize the relationships modeled by key equations in PAGE09 and FUND3.6.

Sources: Hope (2011), Pindyck (2013), Stern (2013) and Tol (2011).

I. Climate Scenarios in FUND3.6 and PAGE09

The impact assessment combines two models (FUND3.6 and PAGE09) and six scenarios altogether. Estimations using FUND3.6 are based on three scenarios (A1B, A2, and B1) and PAGE09 on another three scenarios consisting of the A1 family (A1B, A1FI, and 450 parts per million - ppm).

Table 6.1 summarizes major characteristics of the climate scenarios used for the two models. A1B is a medium emissions scenario in both models. For the comparative analysis, both high and low emissions scenarios have been considered for each model. For FUND3.6, A2 assumes slow economic and technical advances, which in turn lead to high emissions by the end of the current century; B1 assumes that the global economy would undergo structural transformation towards service and information, leading to a lower emissions path. For PAGE09, A1FI characterizes fossil-fuel-intensive growth that presents another high emissions scenario. A low emissions scenario for PAGE09 is one where the global economy achieves stabilization of GHG concentration at 450ppm (Box 6.2).

Table 6.2 presents global climate results from FUND3.6 and PAGE09. Despite using different emissions scenarios, the specific projections for global climate conditions are relatively similar in both models until 2050. These projections differ as time horizon extends to 2100, highlighting the earlier caution about interpreting and using model results in any definite way.

Table 6.1: Summary Description of Climate Scenarios

	A1B	450ppm	B1	A2	A1FI
Population growth	High	-	High	High	High
Economic growth	High	-	High	Slow	High
Type of technology/ economy	Balance use of fossil and non-fossil energy sources	-	Structural transformation toward a service and information economy	Heterogeneous world	Fossil-fuel intensive
Emissions	Medium	Low	Low	High	High

- = not applicable, ppm = parts per million.
Source: IPCC 2000.

Box 6.2: On 450ppm

The United Nations Framework Convention on Climate Change (UNFCCC) commits signatory nations to stabilizing "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference (DAI) with the climate system" (United Nations (1992) Article 2).

While defining the concept of DAI remains controversial (Mann 2009), the 15th Conference of the Parties (COP-15) held in Copenhagen in 2009 reached an accord known as the Copenhagen Accord, in which DAI was defined as an increase in global temperature below 2 0C:

To achieve the ultimate objective of the Convention to stabilize greenhouse-gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2 degrees Celsius, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change. (UNFCCC 2009).

It is generally estimated that achieving such targeted increase in global temperature will require stabilizing greenhouse-gas concentrations at less than 450ppm of CO2 equivalent (IPCC 2007). It is worth noting that atmospheric concentration of carbon dioxide increased by 2.10ppm in 2011 (Blunden and Arndt 2012), and exceeded 400 ppm for the first time since instrumental records began and for approximately the last 3 million years of earth history.

Table 6.2: Global Climate Results in FUND3.6 and PAGE09

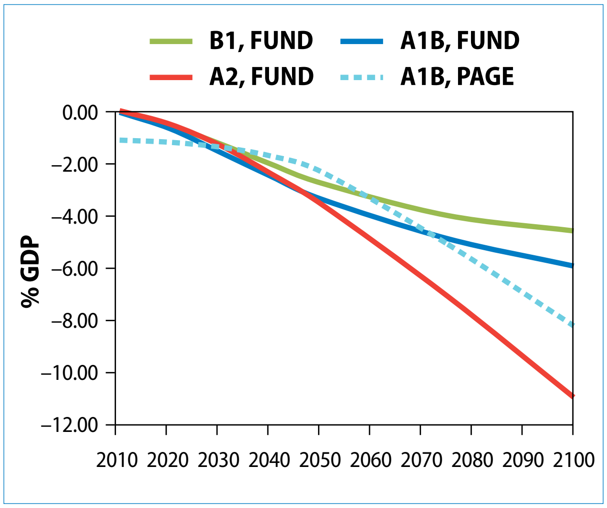
Scenarios	2010	2050	2075	2100
FUND3.6				
Temperature (ºC above pre-industrial levels)				
A1B	0.88	2.11	2.94	3.68
A2	0.88	1.94	2.70	3.49
B1	0.88	1.98	2.61	3.07
Carbon dioxide (ppm)				
A1B	411.26	610.06	717.01	793.76
A2	408.18	553.67	667.74	811.86
B1	408.26	542.26	571.61	569.77
Sea-level rise (m)				
A1B	0.11	0.31	0.50	0.71
A2	0.11	0.30	0.47	0.66
B1	0.11	0.30	0.47	0.63
PAGE09				
Temperature (ºC above pre-industrial levels)				
A1FI	0.77	2.25	3.61	4.63
A1B	0.77	1.98	3.05	3.86
450ppm	0.77	1.89	2.35	2.51
Carbon dioxide (ppm)				
A1FI	400.87	610.03	748.21	882.06
A1B	400.87	535.32	616.95	703.38
450ppm	400.87	459.07	447.93	435.28
Sea-level rise (m)				
A1FI	0.15	0.30	0.48	0.70
A1B	0.15	0.29	0.45	0.63
450ppm	0.15	0.29	0.42	0.54

m = meter, ppm = parts per million.
Source: ADB study team.

II. Regional Economic Impacts of Climate Change

The economic impacts of climate change to the Pacific region as a whole are presented in Figure 6.1 (FUND3.6) and Figure 6.2 (PAGE09). Results should be interpreted as percentage deviations from a baseline situation without projected changes in climate conditions. Both models suggest the total costs of climate change measured in percentage of GDP increase every year. Estimates from FUND3.6 indicate costs ranging between 2.7% and 3.5% of annual GDP equivalent in 2050, increasing to between 4.6% and 10.9% by 2100. Impacts are highest under the A2 scenario, which assumes slower economic growth. Impacts are lowest in the B1 scenario, which represents the coolest climate and relatively prosperous countries. Note in Figure 6.1 that for a similar emissions scenario (A1B), PAGE09 estimates a lower cost than FUND3.6 by 2050, but a higher cost than FUND3.6 in 2100.

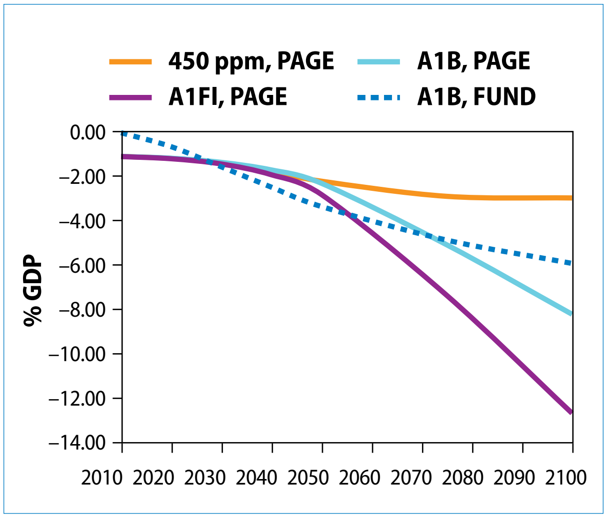
Figure 6.1: Climate Change Cost in the Pacific (FUND3.6)



Source: ADB study team.

Figure 6.2 shows the estimated economic cost of climate change using PAGE09. Similar patterns of economic cost projections are observed. PAGE09 provides estimates of economic costs ranging between 2.2% and 2.8% of annual GDP equivalent

Figure 6.2: Climate Change Cost in the Pacific (PAGE09)



Source: ADB study team.

in 2050. These economic costs range between 2.9% and 12.7% by 2100 depending on the emissions scenarios. Costs are highest under the A1FI scenario. For purposes of illustration, Figure 6.2 also shows FUND3.6 estimates under the A1B scenario.

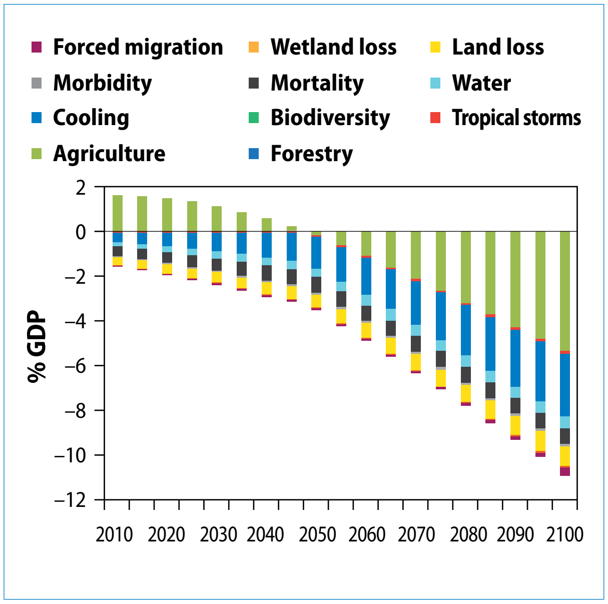
Overall, regardless of which model is used, the results suggest net negative impacts of climate change for the Pacific by 2050 in all scenarios. Losses are projected to rise over time under all scenarios, and would be largest with high emissions scenarios (A2 and A1FI). With the A1FI scenario, where the world stays on the current fossil-fuel intensive growth model, total climate change cost in the Pacific reaches 12.7% of annual GDP equivalent by 2100. The fossil-fuel-intensive growth path causes high degrees of warming, with more frequent catastrophic climate events offsetting gains from rapid economic growth. With the A2 scenario, another high emissions scenario that results from slow economic and technological progress, the climate change cost rises to 10.9% of the region's annual GDP equivalent by 2100.

Despite the global effort to diversify energy sources towards non-fossil-fuel energy under the A1B scenario, the economic damage to the Pacific is expected to range between 5.9% and 8.2% of its annual GDP equivalent by the end of the 21st century. This would imply that the costs of climate change would offset nearly all gains of economic growth from 2100 onwards. Even under a low emissions scenario (B1), in which the global economy is assumed to restructure itself to be service-oriented, the economic loss reaches 4.6% of the region's annual GDP equivalent by 2100 using FUND3.6. If atmospheric concentration of greenhouse gases were to reach 450ppm, the economic cost would be smaller but would still rise to between 2% and 3% of GDP by 2100.

III. Sectoral Composition of Total Economic Impact

Climate change has a range of impacts on different sectors (Figure 6.3). The sectoral composition of climate change impacts is based on the A2 scenario of FUND3.6. While the agriculture sector may initially gain from relatively mild warming until 2050, these impacts would be negative by 2050 across all sectors, including agriculture. These negative

Figure 6.3: Sectoral Composition of Climate Change Costs (FUND3.6 and A2 Scenario)



Source: ADB study team.

impacts would continue to increase over the period 2050–2100.

The model projects adverse effects on yields that would accumulate to an estimated economic loss of $1,957 million or 5.4% of the region's annual GDP equivalent by 2100. The negative effect on agriculture would contribute the most to the total economic cost of climate change in the Pacific—approximately half of total economic cost.

Cooling cost follows second. A warmer climate would put pressure on the rapidly rising energy demand for space cooling in households and in buildings around the Pacific. The future temperature rise implies an increase in cooling demand. When considering income and population growth in the urban areas, the cost of cooling is estimated to reach $1,017 million or 2.8% of the region's annual GDP equivalent by 2100.

Economic impacts in the coastal areas are also significant. The impacts in the coastal areas consist of three components: dryland loss, wetlands loss, and forced migration (economic cost associated with displacement and relocation). The total impact in the coastal areas, through all three channels, is projected to be $469 million or 1.3% of the region's annual GDP equivalent by 2100. Land-loss would account for most of the total coastal impact. The cost of forced migration would become significant only toward the end of the period horizon with the rising sea level. Wetland losses would be relatively small until the end of the period.

Morbidity and mortality together are expected to cost the Pacific region about $296 million or 0.8% of annual GDP equivalent by 2100. Notably, mortality cost would rise fast due to a sharp increase in respiratory disorders until around 2040 before stabilizing somewhat over the period 2050 to 2100 in terms of a percentage of GDP.

Evidence points to increasing risks of respiratory disease due to global warming. Higher temperature, in and of itself, would not be a cause of respiratory disease such as asthma, allergies, infections, and the like. However, the risk would arise from the increased ground-level ozone in urban areas, the increased frequency and severity of heat waves causing excessive heat and bad air pollution, and the expansion of communicable diseases into the higher latitudes. Extreme weather events would also lead to an increased number of respiratory diseases, like the outbreak of infectious respiratory diseases during or in the aftermath of a severe storm and flood. Vulnerable populations would need the most support in such cases.

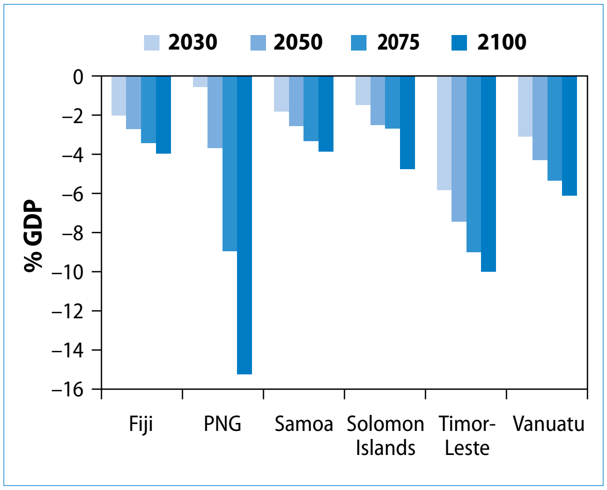
IV. Country-level Cost of Climate Change

The aggregated regional economic impact hides a high variation across different countries. Figure 6.4 shows country-level economic impacts of climate change in the six selected Pacific DMCs. Note that all simulation results presented in this section are based on the A2 scenario of FUND3.6.

The results suggest that PNG would experience the most significant losses from projected climate change, reaching 15.2% of its GDP by 2100, followed by Timor-Leste (10.0%), Vanuatu (6.2%), Solomon Islands (4.7%), Fiji (4.0%) and Samoa (3.8%).

Figure 6.5 presents the country-level economic impacts by sector for each of the six selected Pacific DMCs. For most countries, agriculture and cooling are the major channels for economic impacts of climate change. The impact of agriculture would be significant in all countries but Samoa, with the share of the total economic impact ranging from 33.7% in Solomon Islands to 56.4% in Timor-Leste in 2100. The economic burden of cooling would be significant in all six countries, ranging from 23.6%

Figure 6.4: Country-Specific Cost of Climate Change (FUND3.6 and A2 Scenario)



Source: ADB study team.

of the total cost in Vanuatu to 43.0% in Samoa in 2100. Mortality would also be an important factor for increased economic cost in Fiji, Samoa, and Solomon Islands. For PNG, land loss would be an important channel. For Samoa and Vanuatu, tropical storms would be costly.

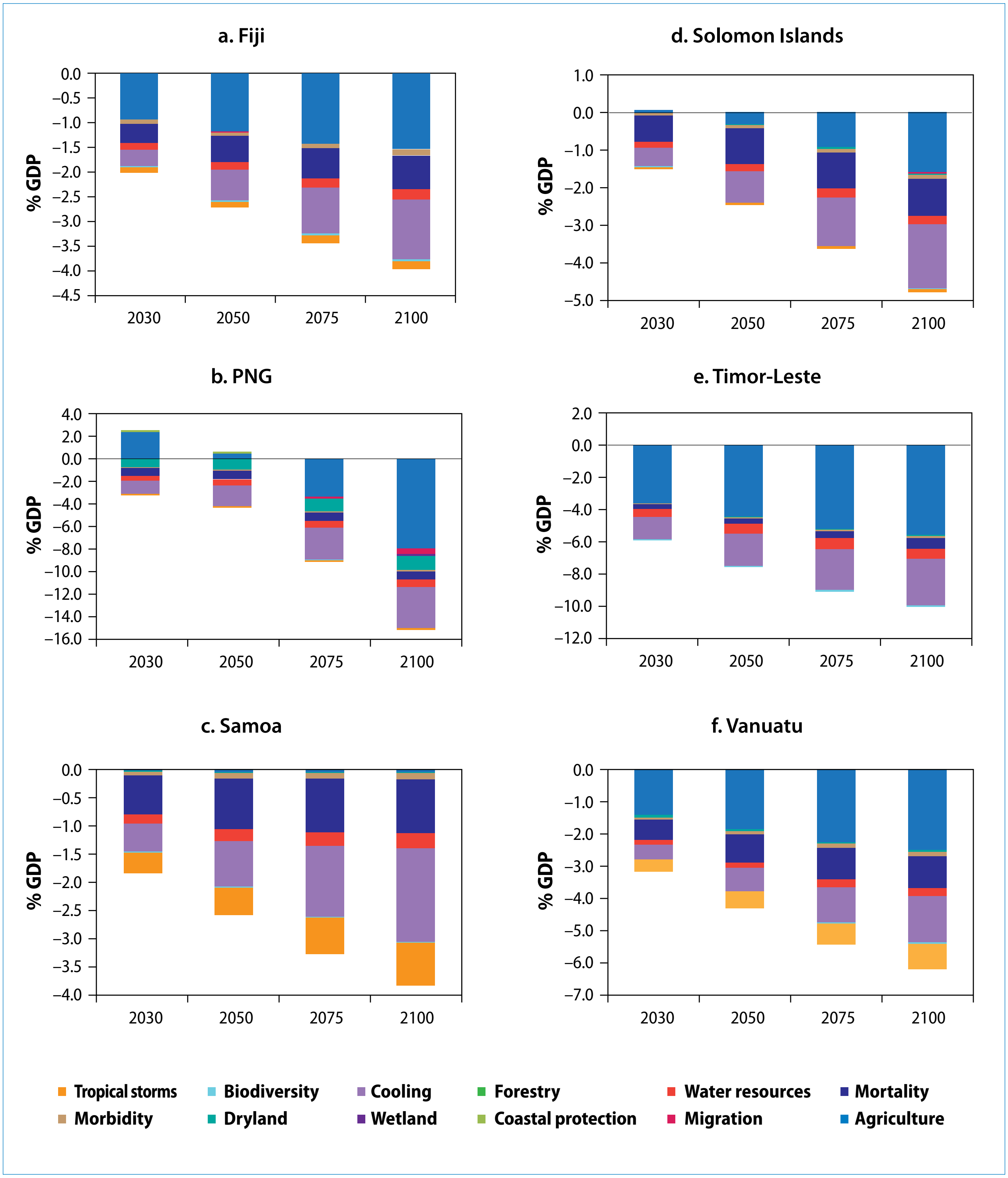
V. Preparing for Catastrophic Risk

An increasing number of recent extreme weather events have raised concerns about potentially severe impacts of extreme weather and the cost of necessary adaptation. Rare but high-impact events complicate adaptation planning. On one hand, adapting to the average climate outcomes might mean overlooking potentially devastating damages and losses beyond the adaptation capacity. On the other hand, while preparing for the worst-case scenario might help avert such damages, it would imply much higher adaptation costs. A stochastic economic analysis may help in this context by offering some clues regarding the optimal or most appropriate level of adaptation.

This section presents the probabilistic cost of climate change under different climate and policy scenarios using the PAGE09 model, which could provide useful information for adaptation planning. It is important to note that the simulation outcomes are probabilistic in nature.

Although the global mean temperature is projected to be 4.7°C on average by 2100 based on

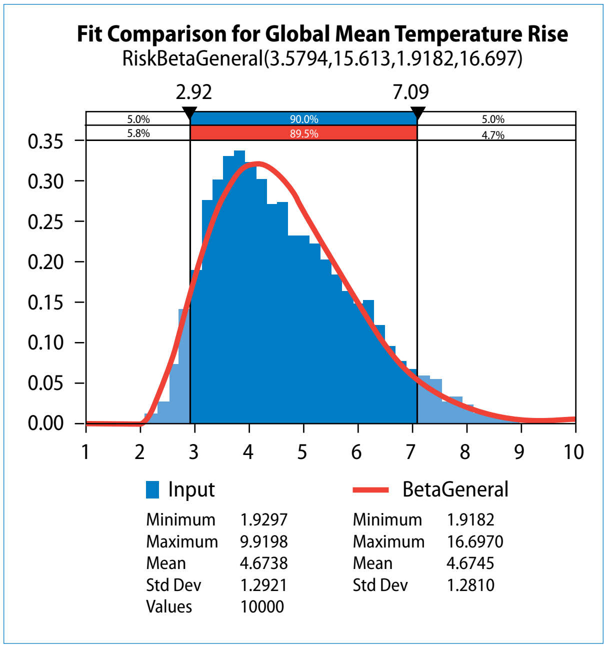
Figure 6.5: Cost of Climate Change by Sector (FUND3.6 and A2 Scenario)



Source: ADB study team.

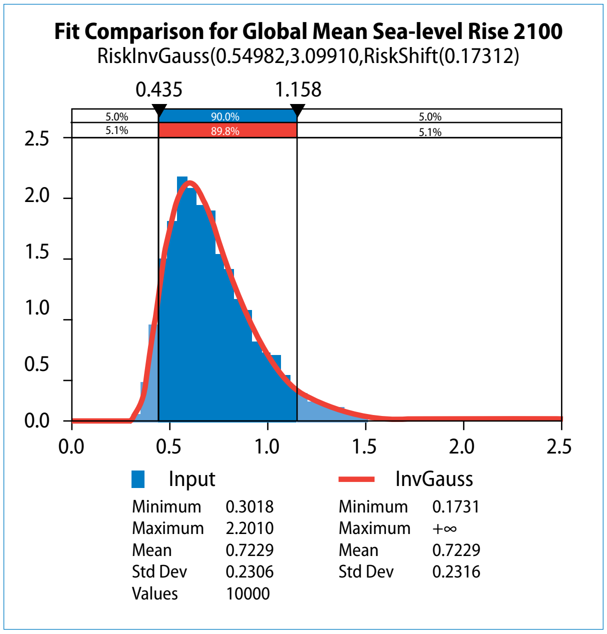
a wide array of existing climate models, there is a 5% chance that the temperature level could increase beyond 7.1°C under the A1FI scenario (Figure 6.6). Similarly, there is a 5% probability that sea level would rise above 1.2 meters by 2100 (Figure 6.7).

Figure 6.6: Probability Distribution of Global Mean Temperature Rise under A1FI Scenario (PAGE09)



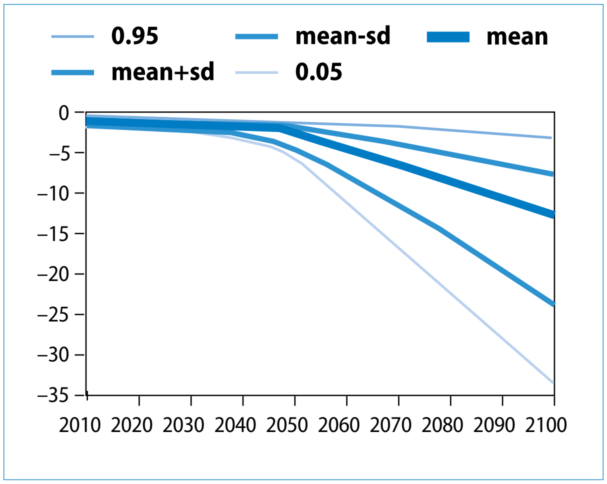
Source: ADB study team.

Figure 6.7: Probability Distribution of Global Sea-Level Rise under A1FI Scenario (PAGE09)



Source: ADB study team.

Figure 6.8: Probabilistic Cost of Climate Change under A1FI Scenario



Source: ADB study team.

Catastrophic events are rare but costly. While PAGE09 estimated the economic damage of climate change at 13% of GDP equivalent on average in 2100 under the A1FI scenario (Figure 6.8), there is a 5% chance that the cost of climate change impacts could be as high as 34% of regional GDP equivalent (Figure 6.8).

VI. Economics of Adaptation in the Pacific

Adaptation measures to climate change are essential to containing the impact of climate change within manageable limits and to protecting the poor and the most vulnerable from an unduly high burden. The cost of adaptation would not be negligible, but uncertainties surrounding climate change make estimation of such cost challenging. Nevertheless, estimates of adaptation costs provide useful information to help decision makers in Pacific DMCs in designing their national strategies for adaptation as well as guide the international community in the climate negotiations.

Tables 6.3 and 6.4 present estimates of adaptation costs associated with different climate scenarios depending on different time-horizons for adaptation targets. These should be interpreted as the cost of recovering the lost GDP presented in Section II above. Table 6.3 presents the estimated costs of adaptation when the adaptation targets are to contain the potential climate change impacts until 2100, while Table 6.4 assumes adaptation targets for 2050. The estimated costs reflect the additional investment need for building adaptive capacity in anticipation of future climate change as well as climate-proofing measures in key sectors towards climate-resilient development. Reflecting large climate uncertainties, PAGE09 produces a probabilistic range of climate conditions for each scenario. For each climate scenario, the annual average cost of adaptation between now and 2050 and the range of estimates within the 90% confidence interval are provided, both in terms of absolute monetary values and as a percentage of GDP.

Table 6.3 shows that the Pacific region would require $447 million every year until 2050 (approximately 1.5% of GDP) to prepare for the worst scenario (A1FI(a)). The cost could be as high as $775 million or 2.5% of GDP per annum. Adapting to the A1FI(b) scenario would cost the region $284 million annually or 1% of GDP from now until 2050. Obviously, the cost of adapting to future climate impact would depend on the global mitigation effort. The cost of adaptation would be significantly lower under lower emissions scenarios. If the world could manage to stabilize CO_2 concentration below 450ppm, the adaptation cost could be expected to be as low as $158 million or 0.5% of GDP per annum during the same period.

Table 6.4 presents adaptation costs for different scenarios if the region's decision makers would take a shorter-term view (i.e., adaptation targets to limit climate change impacts at certain levels only up to 2050) as opposed to a long-term view presented in Table 6.3. For example, the region would require $157 million or 0.5% of GDP every year until 2050 under A1FI scenario if the targeted adaptation is limited to the impact by 2050 (A1FI), as opposed to $284 million or 1% of GDP under A1FI(b) of Table 6.3. Similarly, adapting to the A1B with a short-term view, which is to keep the impact at 2.0°C temperature rise and 0.3 meter sea-level rise by 2050, would cost the region $126 million or 0.4% of GDP every year until 2050 as opposed to $253 million and 0.9% of GDP under A1B in Table 6.3.

Given the large climate uncertainty, there may be some consideration for a "wait-and-see" approach to adaptation planning. The cost of adaptation would certainly be lower if the adaptation plans are considered for containing the climate change impacts only up to 2050 instead of 2100, thus avoiding a larger investment that might prove

Table 6.3 Annual Average Adaptation Cost over the Period 2010–2050 with 2100 Adaptation Targets

Scenario	Adaptation target	Annual average cost	Range $ million	Annual average cost % GDP	Range % GDP
A1FI(a)	2100 worst case (95th percentile)*	446.7	214.6–775.4	1.52	0.78–2.54
A1FI(b)	2100 (4.5°C, 0.70 m SLR)	284.3	131.1–483.7	0.97	0.48–1.59
A1B	2100 (4.0°C, 0.65 m SLR)	253.1	118.9–438.4	0.86	0.44–1.43
450ppm	2100 (2.5°C, 0.55 m SLR)	158.3	75.2–273.2	0.54	0.27–0.89

GDP = gross domestic product, m = meter, ppm = parts per million, SLR = sea-level rise.
Note: The 95th percentile represents the critical point. Moving beyond, there is a low probability (at 5% chance) that would lead to a catastrophic outcome.
Source: ADB study team.

Table 6.4. Annual Average Adaptation Cost over the Period 2010–2050 with 2050 Adaptation Targets

Scenario	Adaptation target	Annual average cost	Range $ million	Annual average cost % GDP	Range % GDP
A1FI	2050 (2.5°C, 0.30 m SLR)	156.9	75.3–271.8	0.54	0.27–0.89
A1B	2050 (2.0°C, 0.30 m SLR)	126.5	59.7–222.8	0.43	0.22–0.71
450ppm	2050 (1.9°C, 0.30 m SLR)	119.8	57.3–205.5	0.41	0.21–0.67

GDP = gross domestic product, m = meter, ppm = parts per million, SLR = sea-level rise.
Source: ADB study team.

unnecessary later on. On the other hand, there is a risk that the cost of adaptation could rise even higher after 2050, as the short-term horizon did not allow for all the necessary adaptation measures from now until 2050 to prepare for changing climate conditions beyond the specified time horizon. Despite the uncertainty as to the estimated cost of climate change and cost of adaptation, the numbers presented here should provide a good basis for discussion and policy dialogue in adaptation planning and decision making.

References

Blunden, J., and D.S. Arndt, eds. 2012. State of the climate in 2012. *Bulletin of the American Meteorological Society*. 93. S1–S264.

Hope, C. 2011. *The PAGE09 Integrated Assessment Model: A Technical Description*. University of Cambridge, Judge Business School. Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC). 2000. *Special Report on Emissions Scenarios*. A Special Report.

Mann, M.E. 2009. Defining dangerous anthropogenic interference. *Proceedings of the National Academy of Social Sciences*. 106. 4065–4066.

Pindyck, R. 2013. *Climate Change Policy: What Do Models Tell US*?. National Bureau of Economic Research. Working Paper 19244.

Stern, N. 2013. The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models. *Journal of Economic Literature*. 51. 838–59.

Tol, R.S.J. 2011. *The Economic Impact of Climate Change on Pacific Island Nations*. Draft report submitted to the Asian Development Bank. Manila.

United Nations Framework Convention on Climate Change (UNFCCC). 2009. *Report of the Conference of the Parties on its Fifteenth Session held in Copenhagen from 7 to 19 December 2009.*

Chapter 7
SUMMARY AND POLICY IMPLICATIONS

I. Summary of Findings

The Pacific nations are uniquely sensitive to the manifold effects of climate change.

The effects of climate change are projected to intensify in the coming decades. The combination and interaction of geographic, economic, environmental, and demographic factors are expected to make the Pacific region particularly sensitive to climate change. All of these factors should therefore be duly taken into account as the region moves forward in adapting to a changing climate.

Average temperatures in the Pacific are expected to rise between 2.0 °C and 3.5°C above the pre-industrial level by 2070.

Climate downscaling shows that annual mean temperatures would increase for all six selected Pacific countries under two different emissions scenarios (A1B and A2). The upward trend is also clear, with the 2070 levels consistently higher than the 2050 levels. Fiji and Samoa would experience a 2.5°C rise by 2070 relative to the pre-industrial level under the A1B scenario. PNG, Solomon Islands, Timor-Leste, and Vanuatu would experience a rise of more than 3°C, while certain areas of these countries would see an increase of nearly 3.5°C by 2070 under the A1B scenario.

The frequency of ENSO cycles is likely to increase, leading to potentially more extreme weather events in the Pacific.

The frequency of El Niño and La Niña could increase in the future. Many GCMs results point to an increase of over 40% in the Pacific under A1B and A2 scenarios. The ENSO-rainfall linkages would also be affected, resulting in unexpected heavy rains and dry episodes. The effects of ENSO on rainfall could be considerable, causing either too much or too little rain depending on the areas and the seasons. Extreme temperatures (the 99th percentile of the distribution of daily maximum data) are expected to increase in all six selected Pacific DMCs. Bobonaro (Timor-Leste) would be the warmest, with the temperature going as high as 44°C by 2070 under the A1B scenario.

Sea-level rise poses risk of inundation to economically important coastal areas in the Pacific.

Although better elevation data are needed for more reliable projections of inundation risk, the impact of sea-level rise would put large coastal areas at risk of inundation. Under the A1B scenario, high-range estimates suggest that by 2100, all Pacific island countries but Kiribati could face a sea-level rise, ranging from 1.2 meters in the Cook Islands to 1.7 meters in Solomon Islands; low-range estimates suggest that sea-level rise to range from 0.5 meter to 1.1 meters for those two islands, respectively. Airports and seaports, road infrastructure, and local communities, all of which are highly concentrated on coastal areas, could sustain significant damage from the expected sea-level rise. Perhaps more importantly, there is risk that the already limited freshwater resources in the region may be severely impacted by increasing salinization.

The effects of climate change on key economic sectors are primarily negative, leading to potentially large losses in agricultural production.

Based on the available evidence and on estimates of the expected effects of climate change, the key economic sectors of the Pacific could sustain potentially high losses in the yields of major agricultural products under the A1B scenario. The effects on important marine natural resources such as coral reefs would be highly negative, but those on fish yields and fisheries economies would be mixed. Also, as a result of a less attractive climate, tourist arrivals are expected to fall along with their contribution to local and national economies. These losses could be further compounded by the adverse impacts of climate change on health and labor productivity.

Climate change may cost the Pacific region between 2.2% and 3.5% of total annual GDP equivalent in 2050 under various emissions scenarios. Larger annual losses are expected by 2100.

The aggregate economic impacts of climate change in the Pacific are negative by 2050 in all scenarios regardless of the model used. By 2050, these annual losses may reach up to 3.5% of GDP under the A2 scenario. By 2100 depending on the specifics of the scenarios, the adverse economic impacts are projected to rise further over time to between 3% of GDP (under the 450ppm scenario) and 13% of GDP (under the A1FI scenario). These potential losses are not negligible and are expected to add to the challenge of achieving long-term sustainable growth and development in the region

For most Pacific DMCs, agriculture and cooling are the major channels for economic impacts of climate change.

Climate change impacts would turn negative across all sectors by 2050 and would continue to increase over the period 2050-2100. While there would be high variation at the national level, the major channels for climate change impacts would be agriculture and cooling. Agriculture would suffer considerably, accounting for 33.7% to 56.4% of the total economic impact in 2100 under the A2 scenario. Cooling costs would rise high, explaining 23.6% to 43.0% of the total economic cost in 2100 also under the A2 scenario. Mortality would also be an important factor for increased economic cost, especially with a sharp increase in respiratory diseases by 2050. Economic damage from land loss would also be large.

Substantial investment is needed to prepare the Pacific for climate change.

The estimated cost for achieving climate-resilient development reflects the additional investment for offsetting the impacts of climate change and includes measures for building climate change adaptive capacity as well as climate-proofing for key sectors. To prepare for the worse of the high emissions scenario A1FI, the funding requirement every year until 2050 could average $447 million or 1.5% of GDP and could go as high as $775 million or 2.5% of GDP. Based on the mean outcomes of climate simulation for the high emissions scenario, adaptation may cost the region $284 million or 1% of GDP per year until 2050. The adaptation cost would be significantly lower under lower emissions scenarios, reaching $253 million per year or 0.9% of GDP under the A1B scenario.

II. Policy Implications

Mainstreaming climate change actions in development planning is crucial to minimize the impacts of climate change.

Climate change is not a stand-alone environmental issue but a development agenda that the Pacific DMCs need to give high priority. If not adequately addressed, climate change could overturn the region's development achievements. As early as the 1990s, the Pacific DMCs had already articulated climate change as a priority, formalizing this in a policy statement entitled *Pacific Plan for Strengthening Regional Coordination and Integration and the Pacific Island Framework for Action on Climate Change (2006-2015)*. The effort was aimed at putting climate change into the mainstream of national policies and planning processes, largely drawing financial support and technical assistance from various development and multilateral agencies. A number of Pacific countries formalized their commitments to address climate change, voluntarily building and adopting their respective *National Adaptation Programme for Adaptation (NAPA)*[15] and *National Capacity Self-Assessment (NCSA)*[16] as well as submitting their *National Communication* to the UNFCCC.

Mainstreaming climate change actions requires merging new development efforts into a comprehensive policy framework that combines various sector approaches, policies, and strategies for achieving climate-resilient and sustainable development. To effectively serve as guiding principles, adaptation to climate change needs to be well-integrated into a comprehensive policy framework. Such climate mainstreaming should be harmonized with existing climate change programs and policies at both the sectoral and national level.

Numerous guidelines prepared by development agencies are available to effectively implement climate mainstreaming. These guidelines highlight the need to: (i) step up efforts to increase public awareness on climate change issues, (ii) conduct more robust research to better understand climate change and its costs, impacts, and solutions in the local context, (iii) build up technical capacity to improve climate information and dissemination, (iv) enhance policy and planning coordination among agencies to promote cross-sectoral cooperation, (v) adopt a holistic approach in building the adaptive capacity of vulnerable groups to shocks and in increasing their resilience to disasters caused by climate change, and (vi) promote low-carbon development with lower GHG emissions wherever appropriate in line with the national and regional sustainable development strategy.

Putting these climate mainstreaming guidelines into action requires strong political commitment from the government and firm institutional support and cooperation from the various national and local agencies. There is also a need to encourage multi-stakeholder participation in the governance and decision-making process. On top of these, adequate funding must be provided for the design and implementation of action plans and programs as well as for the human resource capacity to implement them effectively—two requirements that both pose a significant constraint to climate change undertakings.

A forward-looking adaptation strategy is key to addressing the multitude of climate change impacts, with low-regret options and built-in flexibility as basis for a robust adaptation pathway.

To effectively address a wide range of uncertain climate outcomes, national development planning efforts should consider adopting a forward-looking adaptation strategy. Such a strategy needs thorough appraisal and screening of all available and potential adaptation measures to enable the country at risk to choose which of them are the most socially acceptable, economically viable, technically feasible, and compliant with local development priorities.

A robust adaptation pathway is one that allows for flexibility in dealing with future climate vulnerability in the face of newly available evidence. It requires the continued monitoring and review of ongoing climate change measures to avoid locking in long-term investments in potentially inefficient undertakings.

Since climate impacts vary in degrees and across sectors, building sectoral resilience to climate change critically requires the identification of sector-specific low-regret strategies and responses (Table 7.1). Moreover, the harmonious adaptation planning and implementation of these low-regret strategies require cross-sectoral coordination and cooperation.

[15] NAPAs provide a process for least developing countries to identify priority activities that respond to their urgent and immediate needs to climate change. The Pacific countries that have prepared NAPAs are Kiribati, Samoa, Solomon Islands, Tuvalu, and Vanuatu.

[16] NCSA is an integral part of the Global Environment Facility, with focus on strengthening the capacities of countries to manage their priority environmental issues and contribute to global environmental benefits. NCSAs were completed in the Cook Islands, Fiji, Niue, PNG, Palau, and Timor-Leste. Vanuatu is in the action-plan stage, Kiribati has complied with thematic analyses, and FSM is at the inception stage. NCSA has not started in the RMI and Nauru.

Table 7.1: Sector-Specific Low-Regret Adaptation Options for the Pacific

Agriculture	• Establish an effective climate information system to support farmers and agricultural producers in making informed decisions and plans in response to changing climate and extreme events. • Encourage genetic improvement of crop varieties appropriate to changing climatic conditions, abiotic stresses (drought, flooding, and salinity), and biotic syndromes. • Promote adoption and dissemination of climate-resilient crop varieties. • Develop improved cropping systems and crop-livestock systems to effectively assist adaptation to weather and to environmental alterations brought about by climate change. • Develop an effective agriculture extension system to promote diffusion of climate-resilient farming innovations through appropriate private-public partnerships. • Establish a supportive policy environment to enhance strategic planning of agricultural extension support and infrastructure investments, particularly in areas known to have higher exposure to climate risks. • Make selective investments in irrigation infrastructure where increased future water-deficit stress is expected and where agro-climatic potential would otherwise be high.
Coastal	• Undertake climate-proofing of critical infrastructure. • Adjust current coastal zoning regulations taking into consideration future land coverage and coastal inundation. • Strengthen institutional ability to implement land-zoning restrictions. • Incorporate future coastal-inundation coverage with local flood-risk analysis when doing land-use planning. • Develop plans in coastal management incorporating coral-reef conservation and protection. • Enhance the existing early-warning system to include coastal inundation management schemes. • Plan temporary or permanent migration strategies for rising sea levels, intensified typhoons, and higher tides.
Water	• Where possible, build physical structures that could protect freshwater lenses from salinity intrusion, particularly during wave-surge events. • Build additional water storage and rainwater catchment and harvesting facilities to ensure a buffer or reserve supply of water during water-scarce seasons or in places where salinity has intruded on freshwater resources. • Conduct rigorous water-climate risk assessment to help identify water-deficit hot spots and prioritize appropriate adaptation investments or climate proofing. • Mitigate impacts of weather-related water supply disruptions by tapping a diversity of water supply resources, supporting reuse and recycling programs, enhancing rain harvesting, and tapping the potential of inter-provincial trade from sub-locations with a water supply surplus.
Health	• Establish an information system for health outbreaks and develop the community's capacity to handle them. • Improve public-health facilities and infrastructures. • Create surveillance and warning systems for tracking aeroallergens and for prevalent allergic diseases, particularly asthma and other respiratory diseases. • Develop public-health campaigns on such treatments as oral rehydration therapy for diarrhea or pursue such proactive efforts as using pesticide-impregnated bed nets to prevent malaria. • Expand public access to medicine and equipment for preventing or treating respiratory-related diseases and other ailments such as diarrhea and malaria. • Ensure adequate supply of potable water during floods and take measures to avoid diarrhea incidents.

Adopting a risk-based approach to adaptation and disaster-risk management can help prioritize climate actions and increase the cost-efficiency of adaptation measures.

Weather and climate-related hazards account for the majority of natural disasters in the Pacific, and the economic damage and losses associated with them are substantial. Indeed, despite decades of experience, more needs to be done in terms of disaster-risk reduction and management.

The region's disaster-risk management must be better aligned with climate change risks. This would require (i) appropriate policies, technical skills, and institutional setups to integrate and mainstream climate actions and disaster-risk management into development planning; (ii) establishment in the communities of a cross-sectoral, cross-agency coordination system for disaster-risk management and climate change adaptation; and (iii) improved data and knowledge to assess climate, disaster, and fiscal risks. Through the Pacific Catastrophic Risk Financing Initiative (PCRAFI)[17], ADB is working with the Secretariat of the Pacific Community and with the World Bank to strengthen disaster-risk management and climate change adaptation partnerships among the Pacific DMCs. The risk-based approach of this initiative combines the evaluation of incremental cost and the benefit of adaptation, thus giving priority to practical and cost-efficient measures.

Climate proofing of infrastructure can help improve long-term sustainability.

Infrastructure development in the Pacific already faces considerable climate-related risks that are expected to increase further if not properly managed. Transport, energy, and water-infrastructure projects need to be evaluated against this backdrop. Climate proofing of infrastructure can increase resilience to climate change and reduce risks associated with climate change. For example, climate proofing can improve the durability of roads and bridges, making them better withstand erosion and floods.

Climate proofing should be considered as early as possible in the project design stage. It is important to contain the risks posed by extreme weather events and by potential future climate risks within manageable levels. Although climate proofing could increase the upfront costs of the infrastructure projects, such higher costs could be economically justified by the long lifetime of many infrastructures and by the high probability of climate-related damage in the Pacific. It has become good practice to consider climate-related risks, including disaster risks, at the design stage of all future projects in the region. ADB is also encouraging such practice in all relevant projects by requiring identification of climate change risks at an early stage in project preparation and by addressing the effects of climate change to the extent possible.[18]

Improving knowledge and the capacity to deal with climate uncertainties is a key issue for the Pacific DMCs.

There are difficulties in dealing with climate uncertainties. In the Pacific region, these difficulties are compounded by the lack of comprehensive baseline data and by incomplete local climate information.

Fine-scaled models and various decision-support tools can help provide the authorities of the Pacific DMCs with valuable local-specific information and analysis that can capture local characteristics of climate change impacts. This, in turn, will allow for more effective climate-risk assessment to support development planning and decision making, ranging from public investment in infrastructure to actions at the household and community levels.

To enhance the value and accuracy of climate information, there is a need to further develop climate observation networks and to expand tools and models for climate-risk assessment. These efforts should be complemented by a properly designed capacity-building and awareness-raising program for disseminating climate change information and impact-assessment tools.

[17] PCRAFI is providing disaster-risk modeling and assessment tools for enhanced disaster-risk management, and promotes dialogue on integrated financial solutions for increasing financial resilience to natural disasters and to climate change.

[18] Memorandum, Office of the President, 3 April 2012: Planning Directions – Work Program and Budget Framework 2013–2015 instructs Operations Departments to "continue screening projects for climate risks and climate proofing where needed." Likewise, Memorandum, Strategy and Policy Department, 23 April 2013: Board's request on the contents of Report and Recommendation of the President—Addressing Climate Change Risks, directs operational departments to "(a) identify the climate change risks early at the project preparation stage, (b) analyze the risks, and (c) … ensure that the RRP and/or linked documents address the effects of climate change on the proposed project to the extent feasible (…)"

Improved access to climate finance is critical for ensuring continued economic growth and development for the Pacific DMCs.

Regardless of the climate scenario and modeling approach, the estimated cost of climate change adaptation is considerable. It must be kept in mind, however, that this investment is crucial to guarding against the imminent threat of climate change to the economic well-being and growth of the region. To build this capacity for climate resilience, the Pacific DMCs will require substantial increases in investment, supported as appropriate with financial and technical support from the international community.

Successful adaptation efforts require strong cooperation and coordination among multiple partners within and beyond the Pacific region.

ADB's *Climate Change Implementation Plan for the Pacific* aims at scaling up climate adaptation efforts based on consensus-building among multiple partners, and assisting capacity development of the Pacific DMCs to effectively respond to climate change. The CCIP offers a systematic approach to implementing climate-adaptive investment projects and technical assistance grants along with mitigation actions at the national and regional levels (Box 7.1). Specifically, the CCIP aims to enhance the climate resilience of the Pacific countries and mitigate the impacts of natural-disaster risks through four major measures: (i) mainstreaming adaptation policies, plans, programs and projects into development planning; (ii) strengthening information systems and capabilities to facilitate the adaptation process; (iii) establishing the legal, regulatory, and institutional framework to support policy implementation, and (iv) promoting access to affordable financing for climate-resilient development.

Box 7.1: ADB Climate change Program for the Pacific

Through the *Climate Change Implementation Plan (CCIP)* for the Pacific, ADB is committed to provide a broad spectrum of assistance in implementing national plans for climate change adaptation and mitigation. The Plan proposes a dramatic scaling up of climate change investment and capacity development by helping countries in the region design and implement adaptation and mitigation measures.

The key areas of ADB development assistance for the Pacific are as follows:

A. Climate-proofing roads and other coastal infrastructure. ADB is currently in the process of issuing a series of guidelines for climate proofing-infrastructure.These guidelines present a step-by-step approach to incorporate climate change adaptation measures into infrastructure projects, including transport and energy. Some examples of projects presented in these guidelines are the Timor-Leste Road Rehabilitation Project, the Solomon Islands Road Improvement Project, and the Infrastructure Development Project in the Cook Islands.

B. Promotion of clean energy and energy efficiency. To mitigate the effects of climate change in the Pacific DMCs, ADB is encouraging the region to invest in power generation from renewable resources and to promote energy efficiency. ADB provides assistance through a number of clean-energy initiatives as well as supports the increased use of renewable energy for power generation and the reduction of fuel and power consumption through demand-side management.

Among the forms of support provided by ADB in climate change mitigation are the following:

- Assessment of mini-hydropower generation in Solomon Islands;
- A pilot project in Solomon Islands to switch electricity generation from fossil fuel to coconut oil;
- Hydropower and grid-connected solar plants in Vanuatu;
- Small-scale grid-connected solar plants in rural Tonga;
- Upscaling of wind power, solar power, and hydropower in the FSM;
- Creation and maintenance of an energy-use database in the Cook Islands, PNG, Samoa, Tonga, and Vanuatu;
- Generation of clean energy, including hydropower, in PNG;
- Planning, construction, and rehabilitation of seven hydropower sites in Samoa;
- Replacement of diesel fuel with indigenous biofuels for power generation in the RMI;
- Assistance to foster the establishment of a Clean Energy Fund in Samoa; and
- Assistance to several countries in the Pacific in accessing carbon financing through the Clean Development Mechanism.

C. **Disaster-risk management.** ADB is strengthening disaster-risk management and climate change adaptation partnerships by working closely with the Secretariat of the Pacific Community and the World Bank in preparing the Pacific Catastrophic Risk Financing Initiative (PCRAFI). The PCRAFI provides disaster-risk modeling and assessment tools for enhanced disaster-risk management, and engages in dialogues on integrated financial solutions for increasing financial resilience to natural disasters and to climate change. PCRAFI also developed the region's most comprehensive historical hazard catalogue (115,000 earthquakes and 2,500 tropical-cyclone events) and loss database for major disasters, as well as country-specific hazard models that simulate earthquakes and tropical cyclones. Its outputs also include risk maps showing the geographic distribution of potential losses for each country as well as risk-assessment visualizations, which can be accessed through an open-source web-based platform.

D. **The Pacific Climate Change Program (PCCP).** It aims to streamline support for climate change and to enable the systematic implementation of climate-adaptive investment projects and technical assistance, combined with actions by the Pacific DMCs and supported by a regional technical assistance project.

The PCCP supports a three-pronged strategy:

- Fast-tracking and scaling-up of adaptation and mitigation investment, climate proofing infrastructure, promoting renewable energy, and managing natural resources;
- Building the capacity for strengthening the knowledge, skills, and practices of sector agencies and communities in integrating climate change into development plans; and
- Promoting more effective development partner responses through coordination and harmonization, sharing best practices, and accessing funding from global facilities.

The PCCP focuses on five priority sectors: (i) natural resources management, including agriculture and rural development; (ii) water and sanitation; (iii) urban development; (iv) energy; and (v) transport and information and communication technology. ADB supports the implementation of the PCCP through technical assistance (for policy development, planning and capacity building, and investment design) as well as through project grants and concessional lending (for climate proofing and other adaptation measures, clean-energy technology, and improving energy efficiency).

E. **The Pilot Program for Climate Resilience (PPCR).** This is an adaptation window of the Climate Investment Fund (CIF) and a major element of support to Pacific DMCs. The PPCR aims to achieve "transformational change" through country-led mainstreaming of climate resilience in national development planning and implementation over a five-year period. ADB is working with the World Bank and Pacific regional organizations on regional and national tracks in countries that were selected by the CIF for assistance. ADB is leading implementation in PNG and Tonga, and the World Bank is leading implementation in Samoa; ADB and the World Bank are jointly implementing the regional component.

- **At the country level.** Priority investments relevant to infrastructure were selected for support, based on needs analysis combined with a gap analysis, at national consultative workshops. Example projects in PNG include climate-proofed ports, improved climate change projections, and updated building codes and engineering design criteria. Example projects in Tonga include climate- proofing critical infrastructure; updating legislation, policy, and strategy; and training and capacity-building.
- **At the regional level.** ADB and the World Bank are working with agencies of the Council of Regional Organisation in the Pacific (CROP) on the Strategic Program for Climate Resilience (SPCR), a five-year, $10-million regional program to support more effective integration of climate change adaptation and disaster-risk management to enable countries to become more resilient to climate change.

F. **ADB assistance in accessing internal and external funding sources for Pacific DMCs.** ADB is one of only a few development partners that provide technical assistance, grants, and loans in combination with access to funds for internal and global mitigation and adaptation. ADB has established several internal funds to support its climate change program. It has also forged partnerships with other development institutions for specialized external funds on climate change. Among the external funds that ADB can access on behalf of Pacific DMCs are the Climate Investment Funds, the Global Environment Facility and Least Developed Countries Fund (addressing the urgent and immediate adaptation needs of the least-developed countries as identified by the National Adaptation Programme of Action), the Adaptation Fund (established by the parties to the Kyoto Protocol to finance adaptation projects and programs in developing countries), and the Special Climate Change Fund (providing financing for adaptation; technology transfer; and energy, transport, and industry. agriculture, forestry, and waste management; and economic diversification).

The Economics of Climate Change in the Pacific

The Pacific developing member countries of the Asian Development Bank are highly vulnerable to the predicted effects of climate change, including higher sea levels, intense storm surges and cyclones, erratic rainfall patterns, and major temperature fluctuations. This study identifies the effects and quantifies the costs of these adverse outcomes to the Pacific island economies, with details provided for selected key sectors including agriculture, fisheries, tourism, coral reefs, and human health. It then presents policy recommendations and action steps for the countries to minimize or mitigate these impacts, particularly by mainstreaming climate change in their development plans, adopting forward-looking and risk-based approaches to climate change, and climate-proofing both their programs and infrastructure so that poverty eradication and sustainable development efforts can continue regardless of the vagaries of climate.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to two-thirds of the world's poor: 1.7 billion people who live on less than $2 a day, with 828 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org

Printed on recycled paper

9789292543181

Printed in the Philippines