Climate Change 2007:
Impacts, Adaptation and Vulnerability

Edited by

Martin Parry
Co-Chair,
IPCC Working Group II

Osvaldo Canziani
Co-Chair,
IPCC Working Group II

Jean Palutikof
Head, Technical Support Unit
IPCC Working Group II

Paul van der Linden
Deputy Head, Technical Support Unit,
IPCC Working Group II

Clair Hanson
Deputy Head, Technical Support Unit,
IPCC Working Group II

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to the Fourth Assessment Report of the
Intergovernmental Panel on Climate Change**

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Contents

Foreword

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme in 1988 with the mandate to provide the world community with the most up-to-date and comprehensive scientific, technical and socio-economic information about climate change. The IPCC multivolume assessments have since then played a major role in motivating governments to adopt and implement policies in responding to climate change, including the United Nations Framework Convention on Climate Change and the Kyoto Protocol. The "Climate Change 2007" IPCC Fourth Assessment Report could not be timelier for the world's policy makers to help them respond to the challenge of climate change.

"Climate Change 2007: Impacts, Adaptation and Vulnerability", is the second volume of the IPCC Fourth Assessment Report. After confirming in the first volume on "The Physical Science Basis" that climate change is occurring now, mostly as a result of human activities, this volume illustrates the impacts of global warming already under way and the potential for adaptation to reduce the vulnerability to, and risks of climate change.

Drawing on over 29,000 data series, the current report provides a much broader set of evidence of observed impacts coming from the large number of field studies developed over recent years. The analysis of current and projected impacts is then carried out sector by sector in dedicated chapters. The report pays great attention to regional impacts and adaptation strategies, identifying the most vulnerable areas. A final section provides an overview of the interrelationship between adaptation and mitigation in the context of sustainable development.

The "Impacts, Adaptation and Vulnerability" report was made possible by the commitment and voluntary labor of a large number of leading scientists. We would like to express our gratitude to all Coordinating Lead Authors, Lead Authors, Contributing Authors, Review Editors and Reviewers. We would also like to thank the staff of the Working Group II Technical Support Unit and the IPCC Secretariat for their dedication in organizing the production of another successful IPCC report. Furthermore, we would like to express our thanks to Dr Rajendra K. Pachauri, Chairman of the IPCC, for his patient and constant guidance to the process, and to Drs Osvaldo Canziani and Martin Parry, Co-Chairs of Working Group II, for their skillful leadership.

We also wish to acknowledge and thank those governments and institutions that contributed to the IPCC Trust Fund and supported the participation of their resident scientists in the IPCC process. We would like to mention in particular the Government of the United Kingdom, which funded the Technical Support Unit; the European Commission and the Belgian Government, which hosted the plenary session for the approval of the report; and the Governments of Australia, Austria, Mexico and South Africa, which hosted the drafting sessions to prepare the report.

M. Jarraud
Secretary General
World Meteorological Organisation

A. Steiner
Executive Director
United Nations Environment Director

Preface

This volumes comprises the Working Group II contribution to the IPCC Fourth Assessment (AR4) and contains a Summary for Policymakers, a Technical Summary, the chapters of the Assessment and various annexes. The scope, content and procedures followed are described in the Introduction which follows.

Acknowledgements

This Report is the product of the work of many scientists who acted as Authors, Reviewers or Editors (details are given in the Introduction, Section D). We would like to express our sincere thanks to them for their contribution, and to their institutions for supporting their participation.

We thank the members of the Working Group II Bureau (Edmundo de Alba Alcarez, Abdelkader Allali, Lucka Kajfež-Bogataj, Geoff Love, John Stone and Jean-Pascal van Ypersele), for carrying out their duties with diligence and commitment.

Costs of the Technical Support Unit (TSU) and of Dr Parry were covered by the UK Department for the Environment, Food and Rural Affairs (Defra). The TSU was based in the Met Office Hadley Centre in the UK. We thank David Warrilow (Defra), Dave Griggs and John Mitchell (Met Office) for their support through these agencies.

Four meetings of Authors were held during the preparation of the Report, and the governments of Austria, Australia, Mexico and South Africa, through their Focal Points, kindly agreed to act as hosts. The Approval Session of the Working Group II contribution to the Fourth Assessment was held in Brussels at the generous invitations of the Government of Belgium, through Martine Vanderstraeten, and the European Community, through Lars Mueller. We thank all these governments, institutions and individuals for their hospitality and hard work on behalf of the Working Group II process.

We thank the IPCC Secretary, Renate Christ, and the Secretariat staff Jian Liu, Rudie Bourgeois, Annie Courtin, Joelle Fernandez and Carola Saibante for their efficient and courteous attention to Working Group II needs; and Marc Peeters, WMO Conference Officer, for his work on the organisation of the Brussels Approval Meeting.

Thanks go to ProClim (Forum for Climate and Global Change) and Marilyn Anderson for producing the index to this Report.

Last, but by no means least, we acknowledge the exceptional commitment of the members of the Technical Support Unit throughout the preparation of the Report: Jean Palutikof, Paul van der Linden, Clair Hanson, Norah Pritchard, Chris Sear, Carla Encinas and Kim Mack.

Rajendra Pachauri
Chair IPCC

Martin Parry
Co-Chair IPCC Working Group II

Osvaldo Canziani
Co-Chair IPCC Working Group II

Introduction to the Working Group II Fourth Assessment Report

A. The Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme in 1988, in response to the widespread recognition that human-influenced emissions of greenhouse gases have the potential to alter the climate system. Its role is to provide an assessment of the understanding of all aspects of climate change.

At its first session, the IPCC was organised into three Working Groups. The current remits of the three Working Groups are for Working Group I to examine the scientific aspects of the climate system and climate change; Working Group II to address vulnerabilities to, impacts of and adaptations to climate change; and Working Group III to explore the options for mitigation of climate change. The three previous assessment reports were produced in 1990, 1996 and 2001.

B. The Working Group II Fourth Assessment

The decision to produce a Fourth Assessment Report was taken by the 19th Session of the IPCC at Geneva in April 2002. The report was to be more focussed and shorter than before. The Working Group II contribution was to be finalised in mid-2007.

The IPCC Fourth Assessment is intended to be a balanced assessment of current knowledge. Its emphasis is on new knowledge acquired since the IPCC Third Assessment (2001). This requires a survey of all published literature, including non-English language and 'grey' literature such as government and NGO reports.

Two meetings were held in 2003 to scope the Fourth Assessment, from which emerged the outline for the Working Group II Assessment submitted to IPCC Plenary 21 in November 2003 for approval and subsequent acceptance.

The Report has twenty chapters which together provide a comprehensive assessment of the climate change literature. These are shown in Table I.1. The opening chapter is on observed changes, and addresses the question of whether observed changes in the natural and managed environment are associated with anthropogenic climate change. Chapter 2 deals with the methods available for impacts analysis, and with the scenarios of future climate change which underpin these analyses. These are followed by the core chapters, which assess the literature on present day and future climate change impacts on systems, sectors and regions, vulnerabilities to these impacts, and strategies for adaptation. Chapters 17 and 18 consider possible responses through adaptation and the synergies with mitigation. The two final chapters look at key vulnerabilities, and the interrelationships between climate change and sustainability.

Chapters 9 to 16 of the Working Group II Fourth Assessment consider regional climate change impacts. The definitions of these regions are shown in Table I.2.

Table I.1. *The chapters of the Working Group II contribution to the IPCC Fourth Assessment.*

Section A. ASSESSMENT OF OBSERVED CHANGES

1. Assessment of observed changes and responses in natural and managed systems

Section B. ASSESSMENT OF FUTURE IMPACTS AND ADAPTATION: SYSTEMS AND SECTORS

2. New assessment methodologies and the characterisation of future conditions
3. Freshwater resources and their management
4. Ecosystems, their properties, goods and services
5. Food, fibre and forest products
6. Coastal systems and low-lying areas
7. Industry, settlement and society
8. Human health

Section C. ASSESSMENT OF FUTURE IMPACTS AND ADAPTATION: REGIONS

9. Africa
10. Asia
11. Australia and New Zealand
12. Europe
13. Latin America
14. North America
15. Polar regions (Arctic and Antarctic)
16. Small islands

Section D. ASSESSMENT OF RESPONSES TO IMPACTS

17. Assessment of adaptation practices, options, constraints and capacity
18. Inter-relationships between adaptation and mitigation
19. Assessing key vulnerabilities and the risk from climate change
20. Perspectives on climate change and sustainability

Table I.2. *Countries and territories by region (see Chapters 9 to 16) for the Working Group II Fourth Assessment.*

Africa

Algeria	Angola	Benin	Botswana
Burkina Faso	Burundi	Cameroon	Central African Republic
Chad	Congo	Congo, Democratic Rep. of	Côte d'Ivoire
Djibouti	Egypt	Equatorial Guinea	Eritrea
Ethiopia	Gabon	Gambia	Ghana
Guinea	Guinea-Bissau	Kenya	Lesotho
Liberia	Libya	Madagascar	Malawi
Mali	Mauritania	Morocco	Mozambique
Namibia	Niger	Nigeria	Reunion
Rwanda	Senegal	Sierra Leone	Somalia
South Africa	Sudan	Swaziland	Tanzania
The Gambia	Togo	Tunisia	Uganda
Zambia	Zimbabwe		

Asia

Afghanistan	Bahrain	Bangladesh	Bhutan
Brunei Darussalam	Cambodia	China	East Timor
India	Indonesia	Iran, Islamic Republic of	Iraq
Israel	Japan	Jordan	Kazakhstan
Korea, Dem. People's Rep.	Korea, Republic of	Kuwait	Kyrgyz Republic
Laos	Lebanon	Malaysia	Mongolia
Myanmar	Nepal	Oman	Pakistan
Papua New Guinea	Philippines	Qatar	Russia – East of the Urals
Saudi Arabia	Singapore	Sri Lanka	Syria
Tajikistan	Thailand	Turkey	Turkmenistan
United Arab Emirates	Uzbekistan	Vietnam	Yemen

Australia and New Zealand

Australia	New Zealand

Europe

Albania	Andorra	Armenia	Austria
Azerbaijan	Belarus	Belgium	Bosnia and Herzegovina
Bulgaria	Croatia	Czech Republic	Denmark
Estonia	Finland	France	Georgia
Germany	Greece	Hungary	Ireland
Italy	Latvia	Liechtenstein	Lithuania
Luxembourg	Macedonia	Moldova, Republic of	Monaco
Montenegro	Norway	Poland	Portugal
Romania	Russia – West of the Urals	San Marino	Serbia
Slovak Republic	Slovenia	Spain	Sweden
Switzerland	The Netherlands	Ukraine	United Kingdom
Vatican City, State of			

Polar Regions

Antarctic	North of 60°N (including Greenland and Iceland)

Latin America

Argentina	Belize	Bolivia	Brazil
Chile	Colombia	Costa Rica	Ecuador
El Salvador	French Guiana	Guatemala	Guyana
Honduras	Mexico	Nicaragua	Panama
Paraguay	Peru	Suriname	Uruguay
Venezuela			

North America

Canada	United States of America

Small islands: states and non-autonomous small islands (this list is not definitive)

Anguilla	Antigua and Barbuda	Aruba	Ascension Island
Bahamas	Barbados	Bermuda	Cape Verde
Christmas Island	Comoros	Cook Islands	Cuba
Cyprus	Dominica	Dominican Republic	Fed. States of Micronesia
Fiji	Grenada	Haiti	Jamaica
Kiribati	La Réunion	Maldives	Malta
Marshall Islands	Mauritius	Nauru	Palau
Pitcairn Islands	Saint Kitts and Nevis	Saint Lucia	Saint Vincent & Grenadines
Samoa	Saint Pierre & Miquelon	São Tomé & Príncipe	Seychelles
Solomon Islands	Tonga	Trinidad and Tobago	Tuvalu
Vanuatu			

C. Cross-chapter case studies

Early in the writing of the Working Group II contribution to the Fourth Assessment, there emerged themes of environmental importance and widespread interest which are dealt with from different perspectives by several chapters. These themes have been gathered together into 'cross-chapter case studies', which appear in their entirety at the end of the volume and are included in the CD-ROM which accompanies this volume. A 'roadmap' in Table I.3 of this volume shows where the cross-chapter case study material appears in the individual chapters. Where material appears in the individual chapters which contributes to these case studies, it is presented against a blue background.

The four cross-chapter case studies are:

1. The impact of the European 2003 heatwave
2. Impacts of climate change on coral reefs
3. Megadeltas: their vulnerabilities to climate change
4. Indigenous knowledge for adaptation to climate change

D. Index and database of regional content

This Assessment is based on the review of a very large amount of literature for all parts of the world. For those interested in accessing this literature for a given region, a regional index is provided. This is in the form of a datebase on the CD-ROM which accompanies this volume. This database contains in full all references in this volume and can be viewed by region and topic.

E. Procedures followed in this Assessment by the authors, reviewers and participating governments

In total, the Working Group II Fourth Assessment involved 48 Co-ordinating Lead Authors (CLAs), 125 Lead Authors (LAs), and 45 Review Editors (REs), drawn from 70 countries. In addition, there were 183 Contributing Authors and 910 Expert Reviewers.

Each chapter in the Working Group II Fourth Assessment had a writing team of two to four CLAs and six to nine LAs. Led by the CLAs, it was the responsibility of this writing team to produce the drafts and finished version of the chapter. Where necessary, they could recruit Contributing Authors to assist in their task. Three drafts of each chapter were written prior to the production of the final version. Drafts were reviewed in two separate lines of review, by experts and by governments. It was the role of the REs (two to three per chapter) to ensure that the review comments were properly addressed by the authors.

The authors and REs were selected by the Working Group II Bureau from the lists of experts nominated by governments. Due regard was paid to the need to balance the writing team with proper representation from developing and developed countries, and Economies in Transition. In the review by experts, chapters were sent out to experts, including all those nominated by governments but not yet included in the assessment, together with scientists and researchers identified by the Working Group II Co-Chairs and Vice-Chairs from their knowledge of the literature and the global research community.

F. Communication of uncertainty in the Working Group II Fourth Assessment

A set of terms to describe uncertainties in current knowledge is common to all parts of the IPCC Fourth Assessment, based on the *Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties*[1], produced by the IPCC in July 2005.

Description of confidence

On the basis of a comprehensive reading of the literature and their expert judgement, authors have assigned a confidence level to the major statements in the Report on the basis of their assessment of current knowledge, as follows:

Terminology	*Degree of confidence in being correct*
Very high confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than a 1 out of 10 chance

Description of likelihood

Likelihood refers to a probabilistic assessment of some well-defined outcome having occurred or occurring in the future, and may be based on quantitative analysis or an elicitation of expert views. In the Report, when authors evaluate the likelihood of certain outcomes, the associated meanings are:

Terminology	*Likelihood of the occurrence/ outcome*
Virtually certain	>99% probability of occurrence
Very likely	90 to 99% probability
Likely	66 to 90% probability
About as likely as not	33 to 66% probability
Unlikely	10 to 33% probability
Very unlikely	1 to 10% probability
Exceptionally unlikely	<1% probability

[1] http://www.ipcc.ch/activity/uncertaintyguidancenote.pdf

Table I.3. *Cross-chapter Case Studies: location in text.*

Topic:	Chapter:	Location in chapter:
The impact of the European 2003 heatwave		
Scene-setting and overview		
The European heatwave of 2003	Chapter 12	12.6.1
Impacts on sectors		
Ecological impacts of the European heatwave 2003	Chapter 4	Box 4.1
European heatwave impact on the agricultural sector	Chapter 5	Box 5.1
Industry, settlement and society: impacts of the 2003 heatwave in Europe	Chapter 7	Box 7.1
The European heatwave 2003: health impacts and adaptation	Chapter 8	Box 8.1
Impacts of climate change on coral reefs		
Present-day changes in coral reefs		
Observed changes in coral reefs	Chapter 1	Section 1.3.4.1
Environmental thresholds and observed coral bleaching	Chapter 6	Box 6.1
Future impacts on coral reefs		
Are coral reefs endangered by climate change?	Chapter 4	Box 4.4
Impacts on coral reefs	Chapter 6	Section 6.4.1.5
Climate change and the Great Barrier Reef	Chapter 11	Box 11.3
Impact of coral mortality on reef fisheries	Chapter 5	Box 5.4
Multiple stresses on coral reefs		
Non-climate-change threats to coral reefs of small islands	Chapter 16	Box 16.2
Megadeltas: their vulnerabilities to climate change		
Introduction		
Deltas and megadeltas: hotspots for vulnerability	Chapter 6	Box 6.3
Megadeltas in Asia		
Megadeltas in Asia	Chapter 10	Section 10.6.1, Table 10.10
Climate change and the fisheries of the lower Mekong – an example of multiple stresses on a megadelta fisheries system due to human activity	Chapter 5	Box 5.3
Megadeltas in the Arctic		
Arctic megadeltas	Chapter 15	Section 15.6.2
Case study of Hurricane Katrina		
Hurricane Katrina and coastal ecosystem services in the Mississippi delta	Chapter 6	Box 6.4
Vulnerabilities to extreme weather events in megadeltas in a context of multiple stresses: the case of Hurricane Katrina	Chapter 7	Box 7.4
Indigenous knowledge for adaptation to climate change		
Overview		
Role of local and indigenous knowledge in adaptation and sustainability research	Chapter 20	Box 20.1
Case studies		
Adaptation capacity of the South American highlands´ pre-Colombian communities	Chapter 13	Box 13.2
African indigenous knowledge systems	Chapter 9	Section 9.6.2
Traditional knowledge for adaptation among Arctic peoples	Chapter 15	Section 15.6.1
Adaptation to health impacts of climate change among indigenous populations	Chapter 8	Box 8.6

G. Definitions of key terms

Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where *climate change* refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. *Vulnerability* is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system.