



**THE
GREENHOUSE EFFECT
CLIMATIC CHANGE
AND ECOSYSTEMS**

BOLIN DÖÖS
WARRICK JÄGER
(Editors)

SCOPE 29

The Greenhouse Effect, Climatic Change, and Ecosystems

Edited by

Bert Bolin

Department of Meteorology, University of Stockholm

Bo R. Döös

Department of Meteorology, University of Stockholm

Jill Jäger

Fridtjot Nansen Strasse 1, Karlsruhe

and

Richard A. Warrick

Climatic Research Unit, University of East Anglia, Norwich

*Published on behalf of the
Scientific Committee on Problems of the Environment (SCOPE)
of the
International Council of Scientific Unions (ICSU)
with the support of the United Nations Environment Programme
and the World Meteorological Organisation*

by

JOHN WILEY & SONS

Chichester · New York · Brisbane · Toronto · Singapore

Contents

Preface	xv
List of Contributors	xvii
Statement	xx
by the UNEP/WMO/ICSU Conference on the assessment of the role of carbon dioxide and of other greenhouse gases in climate variations and associated impacts (Villach, Austria, October 1985).	
Executive Summary	xxv
1 The Greenhouse Effect, Climatic Change, and Ecosystems	1
A Synthesis of Present Knowledge	
<i>B. Bolin, J. Jäger, and B. R. Döös</i>	
1.1 Introduction	1
1.2 Previous Assessments of the CO ₂ Problem	3
1.3 Major Findings of the Present Study	7
1.4 Where Do We Go from Here?	27
1.5 References	30
PART A: HOW IS MAN CHANGING THE COMPOSITION OF THE ATMOSPHERE?	
2 Emission of CO₂ into the Atmosphere	35
The Rate of Release of CO ₂ as a Function of Future Energy Developments	
<i>W. Keepin, I. Mintzer, and L. Kristoferson</i>	
2.1 Introduction	35
2.2 The Link Between Energy Use, Economic Activity and CO ₂ Emissions	36

2.3	Uncertainties in Future Energy Use and CO ₂ Emissions	48
2.4	Review of Future Energy and CO ₂ Projections	57
2.5	Bounds on Future CO ₂ Emissions	78
2.6	Conclusions	85
2.7	References	87
3	How Much CO₂ Will Remain in the Atmosphere?	93
	The Carbon Cycle and Projections for the Future	
	<i>B. Bolin</i>	
3.1	Introduction	93
3.2	Carbon in Nature	93
3.3	Carbon in the Atmosphere	96
3.4	Air-Sea Exchange	104
3.5	Carbon in the Sea	107
3.6	Carbon in Terrestrial Biota and Soils	123
3.7	Global Carbon Cycle Modelling	134
3.8	Projections of Future Atmospheric CO ₂ Concentrations	141
3.9	Conclusions	147
3.10	References	150
4	Other Greenhouse Gases and Aerosols	157
	Assessing Their Role for Atmospheric Radiative Transfer	
	<i>H.-J. Bolle, W. Seiler, and B. Bolin</i>	
4.1	Introduction	157
4.2	Trace Gases in the Atmosphere	158
4.3	Likely Future Concentrations of Atmospheric Greenhouse Gases	179
4.4	Radiative Effects of Greenhouse Gases	183
4.5	Aerosols	189
4.6	Conclusions	195
4.7	References	197
PART B: A WARMER CLIMATE		
5	How Will Climate Change?	206
	The Climate System and Modelling of Future Climate	
	<i>R. E. Dickinson</i>	
5.1	Introduction	207

5.2	Causes of Climatic Change	208
5.3	Introduction to Modelling the Climate System	212
5.4	Types of Models—Their Feedbacks	212
5.5	Model Deficiencies	221
5.6	Model Limitations	228
5.7	Review of GCM Results for Increased CO ₂	231
5.8	Reliability of Model Results	256
5.9	Conclusions	262
5.10	References	263
6	Empirical Climate Studies	271
	Warm World Scenarios and the Detection of Climatic Change Induced by Radiatively Active Gases	
	<i>T. M. L. Wigley, P. D. Jones, and P. M. Kelly</i>	
6.1	Introduction	271
6.2	Past Climatic Change	272
6.3	Climate Scenarios	287
6.4	Detection of Climatic Change	295
6.5	Monitoring Requirements	307
6.6	Conclusions	309
6.7	References	311
7	Changing the Sea Level	323
	Projecting the Rise in Sea Level Caused by Warming of the Atmosphere	
	<i>G. deQ. Robin</i>	
7.1	Introduction	323
7.2	Observed Changes of Sea Level and Global Temperature Over the Past Century	325
7.3	Reservoirs and Exchange Rates Within the Hydrological Cycle	332
7.4	Long Period and Catastrophic Changes	346
7.5	Comparison	354
7.6	Conclusions	355
7.7	References	356

PART C: THE IMPACTS ON TERRESTRIAL ECOSYSTEMS

8	The Effects of Increased CO₂ and Climatic Change on Terrestrial Ecosystems	363
	Global Perspectives, Aims and Issues	
	<i>R. A. Warrick, H. H. Shugart, M. Ja. Antonovsky, with J. R. Tarrant and C. J. Tucker</i>	
8.1	Terrestrial Ecosystems, Climate and Man	363
8.2	Focus and Aims	367
8.3	CO ₂ and Climatic Change: Information for Impact Studies	368
8.4	Global Agriculture and Climatic Constraints	371
8.5	Global Forest Ecosystems and Climatic Constraints	381
8.6	Some Further Implications of Ecosystem Change: Summary and Conclusions	387
8.7	References	389
9	CO₂, Climatic Change and Agriculture	393
	Assessing the Response of Food Crops to the Direct Effects of Increased CO ₂ and Climatic Change	
	<i>R. A. Warrick and R. M. Gifford, with M. L. Parry</i>	
9.1	Introduction	393
9.2	The Direct Effects of Increased CO ₂	394
9.3	Perspectives on Climate Impacts	408
9.4	The Impacts of Climatic Change	416
9.5	Summary and Conclusions	459
9.6	References	464
10	CO₂, Climatic Change and Forest Ecosystems	475
	Assessing the Response of Global Forests to the Direct Effects of Increasing CO ₂ and Climatic Change	
	<i>H. H. Shugart, M. Ya. Antonovsky, P. G. Jarvis, and A. P. Sandford</i>	
10.1	Introduction	475
10.2	Time Scales and the Response of Forests	476

10.3 The Direct Impacts of Increasing CO₂ Concentration . . . 486
10.4 Models for Assessing the Impacts of Climatic Change . . . 497
10.5 Studies of the Response of Forests to Climatic Change . . . 502
10.6 Summary and Conclusions 510
Appendix 512
10.7 References 514

Index 523