

Wei Gao
Daniel L. Schmoldt
James R. Slusser
Editors

全球气候变化中的 紫外线辐射

观测、模拟及其对生态系统的影响

UV Radiation in Global Climate Change

Measurements, Modeling
and Effects on Ecosystems



TSINGHUA
UNIVERSITY PRESS



Springer

Wei Gao
Daniel L. Schmoldt
James R. Slusser

全球气候变化中的紫外线 辐射：观测、模拟及其对 生态系统的影响

UV Radiation in Global Climate Change



内 容 简 介

大量研究指出紫外线(UV)辐射对生物有机体有害,并且危害人类健康。对地表UV-B辐射强度增加的研究极大地促进了地基和空基相关观测项目的发展;人们还需要进一步对UV辐射的观测、建模和影响进行深入研究。本书各章描述了过去30年来世界范围内与UV辐射相关的研究工作,涉及的领域有:①UV辐射的当前与预测水平及其对生态系统、人类健康、经济与社会的影响;②UV辐射观测仪器的最新发展,地基和空基观测仪器定标进展情况以及观测方法,建模与有关应用;③全球气候变化对紫外线辐射的影响。

对于涉及全球气候变化、气象学、气候学、环境科学、生物学和农林科学的大专院校高年级本科生、研究生和教师,本书是一本很有价值的参考书。相关领域的科学家、决策者和普通公众亦能受益于此书。

版权所有,侵权必究。侵权举报电话:010-62782989 13701121933

图书在版编目(CIP)数据

全球气候变化中的紫外线辐射:观测、模拟及其对生态系统的影响=UV Radiation in Global Climate Change: Measurements, Modeling and Effects on Ecosystems: 英文/高炜,(美)施默尔特(Schmoldt, D. L.), (美)斯拉瑟(Slusser, J. R.)主编. —北京:清华大学出版社, 2009.11

ISBN 978-7-302-20360-5

I.全… II.①高… ②施… ③斯… III.紫外线-辐射-影响-生态系统-研究-英文
IV.X122 X171

中国版本图书馆CIP数据核字(2009)第153863号

责任编辑:赵彤伟

责任印制:孟凡玉

出版发行:清华大学出版社 地 址:北京清华大学学研大厦A座

<http://www.tup.com.cn> 邮 编:100084

社总机:010-62770175 邮 购:010-62786544

投稿与读者服务:010-62776969, c-service@tup.tsinghua.edu.cn

质 量 反 馈:010-62772015, zhiliang@tup.tsinghua.edu.cn

印 装 者:北京雅昌彩色印刷有限公司

经 销:全国新华书店

开 本:153×235 印 张:35.25 字 数:797千字

版 次:2009年11月第1版 印 次:2009年11月第1次印刷

印 数:1~1500

定 价:158.00元

本书如存在文字不清、漏印、缺页、倒页、脱页等印装质量问题,请与清华大学出版社出版部联系调换。联系电话:(010)62770177 转 3103 产品编号:025568-01

Preface

Over the past three decades, the scientific community has realized the urgency of obtaining a better understanding of the interaction between the earth's atmosphere/biosphere and the sun's radiant energy. Most of the research has focused on the radiant energy balances in the solar and infrared regions of the spectrum, and the way these energy flows affect the climate. During this same time frame, in a related arena, a smaller group of dedicated individuals has concentrated on the role of ultraviolet (UV) radiation as it affects the overall welfare of the planet. Although comprising only a small fraction of the radiation balance that may play a role in global climate change over the next centuries, UV radiation has the capacity to cause direct and more immediate harm to virtually all living organisms and especially to human health. Cumulative high doses of UV radiation are considered a major causal factor in the development of skin cancer and cataracts. Ultraviolet radiation can weaken the human immune system, and can also affect crop production and ocean bio-productivity.

Concerns about the increased levels of UV-B radiation reaching the earth's surface have led to the development of ground- and space-based measurement programs to provide long-term records of its levels. Accurate long-term measurements are difficult to obtain, especially when limited to the bandwidth regions that contain the most harmful solar photons. A core of concerned scientists from across the globe realizes that much work is needed in quantifying the harmful radiation levels and defining their adverse effects. In assessing the effects of UV-B radiation, it is important to realize the complexity of the interactions of living organisms that cause adverse responses with radiant energy directly, as well as in combination with other climate stressors, such as drought, increased temperatures, and CO₂.

This book addresses work that has been conducted throughout the world over the past three decades, such as: (1) current efforts for establishing a climatology of UV radiation; (2) modeling the UV component and its impact on ecosystems, human health, and related economic and social implications; (3) new developments in

UV instrumentation, advances in calibration (ground-based and satellite-based) measurement methods; and (4) the effects of global climate change on UV radiation. All chapters, including the review chapters, have been solicited from renowned scientists in their research fields of UV radiation, meteorology, the environment, and ecosystems. They have presented their work based on research at the global scale, taking into consideration possible future developments. Many new techniques and methods developed from space-ground measurements, mathematical modeling, and remote sensing have recently become available, yet have not previously been presented. This book will be a useful source of reference for undergraduate and graduate students who are involved in the study of global change, environmental science, meteorology, climatology, biology, and agricultural and forest sciences. It will also benefit scientists in related research fields, as well as professors, policy makers, and the general public.

As editors of this book, we wish to express our great appreciation for the contributions of many individuals. We are indebted to the over 50 authors and co-authors within the scientific community who have shared their expertise and contributed much time and effort in the preparation of the book chapters. We also wish to give credit to the numerous funding sources promoting the scientific research performed, and thus the valuable findings shared by the authors. We express our appreciation to the many reviewers and expert scientists who took the time to offer valuable comments and suggestions for the improvement of the book chapters. We acknowledge the management and editorial assistance of Laurie Richards and the technical support of Jonathan Straube of the Natural Resource Ecology Laboratory, Colorado State University and Tsinghua University Press and Springer-Verlag. We especially want to express our appreciation for the support of the Cooperative State Research, Education and Extension Service (CSREES) of the U.S. Department of Agriculture, and the USDA UV-B Monitoring and Research Program at Colorado State University. The efforts of many individuals including Drs. John Moore, John Davis, Steve Liu, Ni-Bin Chang, Mr. George Janson, and Ms. Rita Deike are appreciated.

Dr. Wei Gao
Colorado State University
Fort Collins, CO
Dr. Daniel Schmoldt
U.S. Department of Agriculture
Washington, D.C.

May 2009

List of Contributors

Julia Lee-Taylor¹, Sasha Madronich¹, Christopher Fischer¹, and Bernhard Mayer²

¹National Center for Atmospheric Research, Boulder, Colorado, USA

²Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany

Richard L. McKenzie and J Ben Liley

National Institute of Water and Atmospheric Research (NIWA),

Lauder, Central Otago, New Zealand 9352

NIWA Lauder, Private Bag 50061 Omakau, Central Otago 9352, New Zealand

E-mail: r.mckenzie@niwa.co.nz

E-mail: b.liley@niwa.co.nz

Germar Bernhard, Charles R. Booth, and James C. Ehramjian

5340 Riley Street

Biospherical Instruments Inc., San Diego, CA, USA

E-mail: bernhard@biospherical.com

E-mail: booth@biospherical.com

E-mail: jime@biospherical.com

Claudio Rafanelli, Alessandro Damiani, Elena Benedetti, Sara. De Simone,

Andrea Anav, Luigi Ciattaglia, and Ivo Di Menno

ICES - International Center for Earth Sciences

c/o CNR - Istituto di Acustica "O.M. Corbino"

Area della Ricerca "Roma - Tor Vergata"

via del Fosso del Cavaliere, 100

00133 - Roma, Italy

E-mail: c.rafanelli@e-ices.eu (rafanelli@libero.it)

Jay Herman

Goddard Space Flight Center

Code 613.3

Greenbelt, MD 20771 USA

E-mail: jay.r.herman@nasa.gov

James B. Kerr
Scientist Emeritus of Environment Canada
4396 Kingscote Road, V0R 1N2
Cowichan Bay, British Columbia
E-mail: jbkerr@shaw.ca

Alfio V. Parisi, David J. Turnbull, Peter Schouten, Nathan Downs and Joanna Turner
Centre for Rural and Remote Area Health, University of Southern Queensland,
Toowoomba
Queensland, Australia 4350
E-mail: parisi@usq.edu.au

Wei Gao¹, John M. Davis¹, Roger Tree¹, James R. Slusser¹,
and Daniel Schmoldt²

¹United States Department of Agriculture
UV-B Monitoring and Research Program
Natural Resource Ecology Laboratory
Colorado State University, Fort Collins, CO, USA
E-mail: wgao@uvb.nrel.colostate.edu

²United States Department of Agriculture
Cooperative State Research, Education, and Extension Service
Washington, DC, USA
E-mail: dschmoldt@csrees.usda.gov

Knut Stamnes,¹ Børge Hamre,² and Jakob J. Stamnes²

¹Light and Life Laboratory, Department of Physics and Engineering Physics,
Stevens Institute of Technology, Hoboken, NJ 07030, USA
E-mail: Knut.Stamnes@stevens.edu

²Department of Physics and Technology, University of Bergen, Postboks 7800, 5020
Bergen, Norway
Børge.Hamre@ift.uib.no
E-mail: Jakob.Stamnes@ift.uib.no

Wei Gao¹, Zhiqiang Gao^{1,2}, and Ni-Bin Chang³

¹USDA UV-B Monitoring and Research Program,
Natural Resource Ecology Laboratory,
Colorado State University, Fort Collins, CO, USA
E-mail: wgao@uvb.nrel.colostate.edu
E-mail: zgao@uvb.nrel.colostate.edu

²Institute of Geographical Sciences and Natural Resources Research,
Chinese Academy of Sciences, Beijing, China

³Department of Civil and Environmental Engineering,

University of Central Florida, Orlando, FL 32816, USA
E-mail: nchang@mail.ucf.edu

William F. Barnard¹ and Brian N. Wenny²

¹North Carolina State University

Department of Marine, Earth, and Atmospheric Sciences
Campus Box 8208

Raleigh, North Carolina 27695-8208, USA

E-mail: SBarn46193@aol.com

²MODIS Characterization Support Team (MCST) Sigma Space Corp.

10210 Greenbelt Road, Suite 500

Lanham, MD 20706

E-mail: brian.wenny@gmail.com

Gordon M. Heisler

USDA Forest Service Northeastern Research Station,

c/o SUNY ESF, 5 Moon Library, Syracuse, NY 13210, USA

E-mail: gheisler@fs.fed.us

Ronald J. Ryel¹, Stephan D. Flint¹, and Paul W. Barnes²

¹Department of Wildland Resources and the Ecology Center, Utah State University
Logan, UT 84322-5230, USA

E-mail: ron.ryel@usu.edu

²Department of Biological Sciences, Loyola University New Orleans, LA 70118,
USA

E-mail: pwbarnes@loyno.edu

K. Raja Reddy¹, P.V. Vara Prasad², and Shardendu K. Singh¹

¹Department of Plant and Soil Sciences, Box 9555, 117 Dorman Hall
Mississippi State University, Mississippi State, MS 39762, USA

E-mail: kreddy@pss.msstate.edu

²Department of Agronomy, Kansas State University, Manhattan, KS 66506, USA
E-mail: vara@ksu.edu

Joseph H. Sullivan¹, Linda C. Pope, Betsy M. Sutherland², Paula V. Bennett²,
James E. Blum³, Ann E. Stapleton⁴, and Dennis C. Gitz III⁵

¹Department of Plant Science and Landscape Architecture, 2122 Plant Sciences
Building University of Maryland, College Park, MD 20742, USA

E-mail: jsull@umd.edu

²Brookhaven National Laboratory, P.O. Box 5000
Upton, NY 11973-5000, USA

E-mail: bms@bnl.gov

³Department of Mathematics and Statistics

University of North Carolina at Wilmington, Wilmington, NC 28403, USA

E-mail: blumj@uncw.edu

⁴Department of Biology and Marine Biology

University of North Carolina at Wilmington, Wilmington, NC 28403, USA

E-mail: stapletona@uncw.edu

⁵USDA-ARS, 3810 4th Street, Lubbock, Texas 79415, USA

Richard H. Grant¹, Kent G. Apostol², and Hans F. Schmitz¹

¹Department of Agronomy, Purdue University, West Lafayette, IN 47907-2054, USA

E-mail: rgrant@purdue.edu

E-mail: hschmitz@purdue.edu

²Department of Biological Sciences, Bethel University, St. Paul, MN 55112, USA

E-mail: k-apostol@bethel.edu

Katherine M. Warpeha and Lon S. Kaufman

Department of Biological Sciences m/c 567

University of Illinois at Chicago

900 S. Ashland Ave

Chicago, IL 60607, USA

E-mail: kwarpeha@uic.edu

E-mail: lkaufman@uic.edu

Yadong Qi¹, Gordon M. Heisler², Wei Gao³, Thomas C. Vogelmann⁴, and Shuju Bai⁵

¹Urban Forestry Program, P.O. Box 11288, Southern University

Baton Rouge, LA 70813, USA

E-mail: yadong_qi@subr.edu

²USDA Forest Service Northeastern Research Station, c/o SUNY ESF,

5 Moon Library, Syracuse, NY 13210, USA

E-mail: gheisler@fs.fed.us

³USDA UV-B Radiation Monitoring Program, and Senior Research Scientist,

Natural Resource Ecology Laboratory, Colorado State University

Fort Collins, CO 80523-1499, USA

E-mail: wgao@uvb.nrel.colostate.edu

⁴Botany Department, University of Vermont, Burlington, VT 05405, USA

E-mail: Thomas.Vogelmann@uvm.edu

⁵Department of Computer Science, Southern University

Baton Rouge, LA 70813, USA

E-mail: bais@cmps.subr.edu

Contents

List of Contributors xiii

1 A Climatology of UV Radiation, 1979 – 2000, 65S – 65N 1

1.1 Introduction 1

1.2 Method..... 2

1.3 Results 6

1.3.1 Satellite-Derived UV Climatologies 6

1.3.2 Comparison with Ground-Based Measurements 14

1.3.3 Discussion of Uncertainties 16

1.4 Conclusions 17

Acknowledgements 17

References 18

2 Balancing the Risks and Benefits of Ultraviolet Radiation 21

2.1 Introduction 22

2.2 Long Term Changes in UV_{Ery} 22

2.3 Geographical Variability in UV_{Ery} 23

2.4 Peak UV..... 24

2.4.1 Peak UV Index..... 24

2.4.2 Peak UV Daily Dose..... 28

2.5 Comparing Weighting Functions for Erythema and Vitamin D..... 29

2.6 Seasonal and Diurnal Variation of UV_{Ery} and UV_{VitD} 31

2.7 Global Climatologies of UV_{Ery} and UV_{VitD} 33

2.8 Relationship Between UV_{VitD} and UV_{Ery} 36

2.9 Production of Vitamin D from Sunlight 38

2.10 Calculation of Optimal Times for Exposure to Sunlight 38

2.11 An Inconsistency 42

2.12 Conclusions 44

Acknowledgements 45

References 45

3 Climatology of Ultraviolet Radiation at High Latitudes Derived from Measurements of the National Science Foundation’s Ultraviolet Spectral Irradiance Monitoring Network..... 48

3.1 Introduction 49

3.2	Data Analysis.....	51
3.2.1	Data.....	51
3.2.2	Establishment of Climatologies.....	52
3.2.3	Estimates of Historical UV Indices.....	52
3.3	UV Index Climatology.....	56
3.3.1	South Pole.....	56
3.3.2	McMurdo Station.....	57
3.3.3	Palmer Station.....	59
3.3.4	Ushuaia.....	60
3.3.5	San Diego.....	60
3.3.6	Barrow.....	61
3.4	Climatology of UV-A Irradiance.....	62
3.5	Comparison of Radiation Levels at Network Sites.....	65
3.6	Conclusions and Outlook.....	69
	Acknowledgements.....	70
	References.....	70
4	UV Solar Radiation in Polar Regions: Consequences for the Environment and Human Health.....	73
4.1	Introduction.....	74
4.2	Networks and Databanks.....	76
4.3	Impact of Solar UV on the Environment.....	79
4.3.1	Effect of the Environment on Solar UV.....	85
4.4	Impact of Solar UV on Human Health.....	88
4.4.1	Information and Protection Programs.....	92
4.4.2	Dosimetry, UV Modeling, and Instruments.....	93
4.5	Concluding Remarks.....	98
	References.....	99
5	Changes in Ultraviolet and Visible Solar Irradiance 1979 to 2008.....	106
5.1	Introduction.....	106
5.2	Instrumentation.....	112
5.3	Detection of Long-Term Change.....	121
5.3.1	Radiation Amplification Factor.....	122
5.3.2	Different Definitions of RAF.....	125
5.3.3	Estimating UV Trends: Discussion.....	126
5.3.4	Reduction of UV Irradiance by Clouds and Aerosols.....	128
5.3.5	Stokes Derivation of $C_T = (1 - R)/(1 - R_G)$	130
5.3.6	UV Absorption.....	132
5.3.7	Estimating Zonal Average UV Change.....	132
5.3.8	Estimating UV Trends: Satellites.....	133
5.3.9	Estimating UV Trends: Ground-Based.....	138
5.4	UV in the Polar Regions.....	139

5.5	Human Exposure to UV	140
5.6	UV Index and Units	143
5.7	Action Spectra and Irradiance Trends	143
5.8	UV Summary	151
	Appendix 5.1 Calculating $RAF(\theta)$	153
	Acknowledgements	155
	References	155
6	The Brewer Spectrophotometer	160
6.1	Introduction	160
6.2	History	161
6.3	The Instrument	163
6.3.1	The Fore-Optics	165
6.3.2	The Spectrometer	166
6.3.3	The Photomultiplier Housing	168
6.3.4	Support Electronics	169
6.3.5	The Control Computer	170
6.4	Corrections Applied to Data	170
6.4.1	Dark Count	170
6.4.2	Dead Time	171
6.4.3	Stray Light	172
6.4.4	Temperature Response	172
6.4.5	Neutral Density Filters	173
6.4.6	Cosine Response	173
6.4.7	Internal Polarization	174
6.5	Measurement of Total Ozone	175
6.5.1	Measurement Technique	175
6.5.2	Calibration	177
6.6	Measurement of Spectral UV Radiation	179
6.7	Measurement of Other Atmospheric Variables	181
6.7.1	Vertical Profile of Ozone	182
6.7.2	Atmospheric SO_2	182
6.7.3	Atmospheric NO_2	183
6.7.4	Aerosol Optical Depth	183
6.7.5	Effective Temperature of Atmospheric Ozone	184
6.8	The Brewer Spectrophotometer as a Powerful Research Tool	185
6.9	Summary	186
	Acknowledgements	186
	References	186
7	Techniques for Solar Dosimetry in Different Environments	192
7.1	Introduction	192
7.2	UV Dosimetry and Minimization Strategies	194

7.3	Miniaturization of Polysulphone Dosimeters	195
7.4	Measurements on Plants	197
7.5	Long-Term UV Dosimeters	199
7.6	Vitamin D Effective UV Dosimetry	200
7.7	Discussion and Conclusions	201
	References	202
8	An Ultraviolet Radiation Monitoring and Research Program for Agriculture.....	205
8.1	Introduction	206
8.2	Introduction to the USDA UVMRP (Purpose and History).....	207
8.3	Monitoring Network	208
	8.3.1 Sites and Coverage.....	208
	8.3.2 Data Products Provided by UVMRP	209
8.4	Data Collection and Processing	210
	8.4.1 UV-MFRSR Data Processing.....	212
	8.4.2 Erythemally Weighted UV Irradiance.....	215
	8.4.3 Langley Analysis.....	219
	8.4.4 Data Processing for Other Measurements.....	221
8.5	Derived Products	222
	8.5.1 Optical Depth.....	223
	8.5.2 Daily Column Ozone	224
	8.5.3 Synthetic Spectrum Data.....	225
8.6	Database Design and Website Interface.....	227
	8.6.1 The Data.....	227
8.7	UVMRP's Role in UV-B Agricultural Effects Studies	229
	8.7.1 Mississippi State University.....	230
	8.7.2 Purdue University	230
	8.7.3 Utah State University.....	231
	8.7.4 University of Maryland.....	231
	8.7.5 Washington State University.....	231
	8.7.6 University of Illinois—Chicago	232
	8.7.7 Highlights of Other Collaborations.....	232
8.8	Modeling of Agricultural Sustainability	233
8.9	Future Considerations.....	234
8.10	Summary.....	235
	Acknowledgements	237
	References	237
9	Radiative Transfer in the Coupled Atmosphere-Snow-Ice-Ocean (CASIO) System: Review of Modeling Capabilities	244
9.1	Introduction	245
9.2	Radiative Transfer Modeling	247

9.2.1	Sun-Earth Geometry	247
9.2.2	Spectrum of Solar Radiation	248
9.2.3	Atmospheric Vertical Structure	249
9.2.4	Light Interaction with Absorbing and Scattering Media	250
9.2.5	Equation of Radiative Transfer	256
9.2.6	Surface Reflection and Transmission	257
9.2.7	Radiative Transfer in a Coupled Atmosphere-Snow-Ice-Ocean (CASIO) System	258
9.3	Sample Applications of the Theory	259
9.3.1	Comparison of Modeled Irradiances in CAO Systems	259
9.3.2	Measured and Modeled Radiation Fields in Sea Ice	261
9.3.3	Radiation Trapping in Sea Ice	261
9.3.4	Impact of Ozone Depletion on Primary Productivity	263
9.4	Discussion and Conclusions	264
	Acknowledgements	265
	References	265

10 Comparative Analysis of UV-B Exposure Between Nimbus 7/TOMS

	Satellite Estimates and Ground-Based Measurements	270
10.1	Introduction	271
10.2	Materials and Methods	274
10.2.1	USDA UV-B Dataset	274
10.2.2	TOMS Dataset	274
10.2.3	UV Index	276
10.2.4	Comparative Analysis	276
10.3	Results and Discussion	277
10.3.1	UV-I Daily Change Analysis	277
10.3.2	Analysis of UV-I Variability	279
10.3.3	UV-I Spatial Analysis	281
10.4	Conclusions	287
	Acknowledgements	289
	References	289

11 Ultraviolet Radiation and Its Interaction with Air Pollution

11.1	Introduction	291
11.1.1	Factors Affecting UV Flux at the Earth's Surface	292
11.2	Optics of the Atmosphere	301
11.2.1	Scattering	301
11.2.2	Absorption	303
11.2.3	Emission	304
11.2.4	Atmospheric Optical Depth	304
11.2.5	Single Scatter Albedo	309
11.2.6	Asymmetry Factor	310

11.2.7	Angstrom's Exponent	310
11.3	Models and Measurements	310
11.4	Summary	325
	References	326
12	Urban Forest Influences on Exposure to UV Radiation and Potential Consequences for Human Health	331
12.1	Introduction	332
12.2	Effects of Solar UV on Human Health and Epidemiology	333
12.2.1	Sunburn	333
12.2.2	Skin Types	336
12.2.3	Immune Function	336
12.2.4	Skin Cancers	336
12.2.5	Eye Diseases	339
12.2.6	Sunscreen Effectiveness	339
12.2.7	Positive Impacts	339
12.3	UV Climatology	344
12.3.1	Ozone Trends	344
12.4	Urban Structural Influences	346
12.4.1	Sky Radiance and Diffuse Fraction	346
12.4.2	UV Reflectivity	347
12.4.3	Tree and Building Influences on UV	347
12.4.4	Human Exposure	356
12.5	Public Health Information	357
12.6	Conclusions	358
	Acknowledgements	359
	References	360
13	Solar UV-B Radiation and Global Dimming: Effects on Plant Growth and UV-Shielding	370
13.1	Introduction	371
13.1.1	Global Dimming and UV-B: Potential Effects on Plants	371
13.1.2	Assessing Global Dimming and UV-B Effects on Plant Growth	372
13.2	Methods	374
13.2.1	Field Site	374
13.2.2	Structural and Biomass Measurements	375
13.2.3	UV-A Epidermal Transmittance Measurements	376
13.2.4	Solar UV and PAR Irradiance	376
13.2.5	Statistical Analyses	377
13.3	Results	377
13.3.1	UV-A Epidermal Transmittance	377

13.3.2	Dimming Effects on Biomass and Structure	381
13.4	Discussion	383
13.4.1	Global Dimming and UV-B Effects on Leaf Optical Properties.....	384
13.4.2	Global Dimming and UV-B Effects on Productivity.....	384
13.4.3	Ecological Implications	385
13.5	Concluding Remarks.....	388
	Acknowledgements.....	389
	References.....	389
14	Effects of Ultraviolet-B Radiation and Its Interactions with Climate Change Factors on Agricultural Crop Growth and Yield.....	395
14.1	Introduction.....	396
14.2	Abiotic Stress Factors and Crop Yield	400
14.3	Crop Responses to UV-B and Other Climate Change Factors	401
14.3.1	Specific Effects of UV-B Radiation on Plants.....	402
14.3.2	Strategies for Protection against UV-B Radiation	410
14.3.3	Crop Response to Atmospheric CO ₂ Concentration.....	412
14.3.4	Crop Response to Temperature	413
14.3.5	Crop Response to Drought	414
14.3.6	Crop Response to Multiple Abiotic Stress Factors	416
14.4	Abiotic Stress Tolerance and Cultivar Screening Tools	419
14.5	Climate Change and Aerobiology and Public Health.....	422
14.6	Concluding Remarks.....	423
	Acknowledgements.....	424
	References.....	424
15	Assessment of DNA Damage as a Tool to Measure UV-B Tolerance in Soybean Lines Differing in Foliar Flavonoid Composition.....	437
15.1	Introduction.....	438
15.2	Materials and Methods.....	441
15.2.1	Plant Growth and UV Irradiation	441
15.2.2	Field Sampling	442
15.2.3	Analysis of Phenolics	443
15.2.4	Determination of DNA Lesions—Gel Electrophoresis Method.....	443
15.2.5	Determination of DNA Lesions—Monoclonal Antibody Method	446
15.2.6	Experimental Design and Statistical Analysis.....	446
15.3	Results and Discussion.....	446
15.3.1	Leaf Phenolics	446
15.3.2	DNA Damage	448

15.4	Conclusions.....	452
	Acknowledgements.....	453
	References.....	453
16	Physiological Impacts of Short-Term UV Irradiance Exposures on Cultivars of Glycine Max	458
16.1	Introduction.....	459
16.2	Materials and Methods.....	461
16.2.1	Plant Material and Greenhouse Growth Conditions.....	461
16.2.2	UV Treatment.....	462
16.2.3	UV Exposure Regimes	463
16.2.4	Stomatal Conductance Measurements.....	466
16.2.5	Photosynthesis and Transpiration Measurements.....	467
16.2.6	Pigment Analyses	467
16.2.7	UV-B Absorbing Compounds.....	468
16.3	Results and Discussion.....	469
16.3.1	Stomatal Conductance.....	469
16.3.2	Transpiration	473
16.3.3	Photosynthesis.....	476
16.3.4	Water Use Efficiency.....	478
16.3.5	UV-B Absorbing Compounds and Leaf Pigments.....	478
16.4	Summary and Conclusions.....	481
	Acknowledgements.....	483
	References.....	483
17	UV-Effects on Young Seedlings of Soybean: Effects in Early Development and Long-Term Effects	488
17.1	Introduction.....	488
	Main Objectives	492
17.2	Results and Discussion.....	492
17.2.1	UV Effects on Early Development and Survival of Young Soybean.....	492
17.2.2	Surviving Soybean: the Affect on Seed Production	496
17.2.3	Assessment of Phenylpropanoids in Response to UV.....	498
17.3	Conclusions.....	499
17.4	Methods.....	500
17.4.1	Plant Materials and Accessions	500
17.4.2	Plant Growth and Preparation of Tissue.....	500
17.4.3	Chemicals	501
17.4.4	UV Radiation Sources and Treatments.....	501
17.4.5	Metabolome Studies	501
	Acknowledgements.....	502
	References.....	502