

Contents

Preface	xi
Foreword	xiii
List of figures	xv
List of tables	xix
List of abbreviations and acronyms	xxi
About the author	xxiii
1 The climate system	1
1.1 Why does climate vary from one place to another?	2
1.1.1 Why mountains are colder	4
1.2 Winds and currents: the atmosphere and oceans	6
1.3 The ocean circulation	9
1.3.1 Ocean gyres and the "Roaring Forties" (or Furious Fifties)	9
1.3.2 Winds and ocean currents push against one another	10
1.4 The thermohaline circulation	10
1.5 The great heat-transporting machine	13
1.5.1 The "continental" climate	15
1.5.2 Patterns of precipitation	15
2 From climate to vegetation	21
2.1 Biomes: the broad vegetation types of the world	21
2.2 An example of a biome or broad-scale vegetation type: tropical rainforest	22

2.3	The world's major vegetation types	26
2.4	Understanding the patterns	31
2.5	What favors forest vegetation	31
2.5.1	Why trees need more warmth	32
2.5.2	Why trees need more water	33
2.6	Deciduous or evergreen: the adaptive choices that plants make . .	35
2.7	Cold-climate evergreenness	40
2.8	The latitudinal bands of evergreen and deciduous forest	41
2.9	Nutrients and evergreenness	42
2.10	Other trends in forest with climate	42
2.11	Non-forest biomes	43
2.12	Scrub biomes	43
2.13	Grasslands	44
2.14	Deserts	44
2.15	Biomes are to some extent subjective	45
2.16	Humans altering the natural vegetation, shifting biomes	45
2.17	"Predicting" where vegetation types will occur	46
2.18	Species distributions and climate	48
2.18.1	Patterns in species richness	51
3	Plants on the move	55
3.1	Vegetation can move as the climate shifts	55
3.2	The Quaternary: the last 2.4 million years	55
3.3	Biomes in the distant past	59
3.3.1	Sudden changes in climate, and how vegetation responds . .	63
3.4	The increasing greenhouse effect, and future vegetation change . .	67
3.5	Response of vegetation to the present warming of climate	68
3.6	Seasons as well as vegetation distribution are changing	71
3.7	What will happen as the warming continues?	73
3.7.1	Movement of biomes under greenhouse effect warming . .	76
4	Microclimates and vegetation	79
4.1	What causes microclimates?	79
4.1.1	At the soil surface and below	80
4.1.2	Above the surface: the boundary layer and wind speed . .	80
4.1.3	Roughness and turbulence	83
4.1.4	Microclimates of a forest canopy	84
4.1.5	Under the canopy	86
4.1.6	Big plants "make" the microclimates of smaller plants . .	88
4.1.7	The importance of sun angle	90
4.1.8	Bumps and hollows in the landscape have their own microclimate	92
4.1.9	Life within rocks: endolithic lichens and algae	94
4.1.10	Plants creating their own microclimate	94

4.1.11	Dark colors	95
4.1.12	Protection against freezing	95
4.1.13	Internal heating	95
4.1.14	Volatiles from leaves	95
4.1.15	Utilization of microclimates in agriculture	96
4.2	From microclimates to macroclimates	96
5	The desert makes the desert: Climate feedbacks from the vegetation of arid zones	101
5.1	Geography makes deserts	101
5.2	But deserts make themselves	102
5.2.1	The Sahel and vegetation feedbacks	107
5.2.2	Have humans really caused the Sahelian droughts?	111
5.3	Could the Sahara be made green?	112
5.4	A human effect on climate? The grasslands of the Great Plains in the USA	114
5.5	The Green Sahara of the past	118
5.6	Could other arid regions show the same amplification of change by vegetation cover?	123
5.7	Dust	124
5.7.1	Sudden climate switches and dust.	127
5.8	The future	128
6	Forests	131
6.1	Finding out what forests really do to climate	133
6.2	What deforestation does to climate within a region	136
6.3	Re-afforestation	142
6.4	The remote effects of deforestation	143
6.5	The role of forest feedback in broad swings in climate	144
6.5.1	Deforestation and the Little Ice Age.	144
6.5.2	Deforestation around the Mediterranean and drying in north Africa.	146
6.5.3	Forest feedbacks during the Quaternary	147
6.6	Volatile organic compounds and climate	149
6.7	Forest-climate feedbacks in the greenhouse world	151
7	Plants and the carbon cycle	153
7.1	The ocean	155
7.2	Plants as a control on CO ₂ and O ₂	157
7.3	Methane: the other carbon gas	159
7.3.1	Carbon and the history of the earth's temperature.	161
7.3.2	Plants, weathering and CO ₂	161
7.3.3	Plants, CO ₂ and ice ages	165

7.4	Humans and the carbon store of plants	171
7.5	The present increase in CO ₂	174
7.5.1	The oceans as a carbon sink	176
7.5.2	Seasonal and year-to-year wiggles in CO ₂ level	177
7.6	The signal in the atmosphere	181
7.7	The strength of the seasonal "wobble" in CO ₂	184
7.8	Accounting errors: the missing sink	184
7.9	Watching forests take up carbon	186
7.9.1	Predicting changes in global carbon balance under global warming	188
8	The direct carbon dioxide effect on plants	191
8.1	The two direct effects of CO ₂ on plants: photosynthesis and water balance	191
8.2	Increased CO ₂ effects at the scale of a leaf	192
8.3	Modeling direct CO ₂ effects	193
8.4	What models predict for increasing CO ₂ and global vegetation	194
8.5	Adding climate change to the CO ₂ fertilization effect	195
8.6	Experiments with raised CO ₂ and whole plants	197
8.6.1	The sort of results that are found in CO ₂ enrichment experiments	201
8.6.2	A decline in response with time	202
8.7	Temperature and CO ₂ responses interacting	202
8.8	A few examples of what is found in FACE experiments	203
8.8.1	Forests	203
8.8.2	Semi-desert and dry grassland vegetation	204
8.8.3	Will C ₄ plants lose out in an increased CO ₂ world?	206
8.9	Other FACE experiments	210
8.9.1	FACE studies on agricultural systems	210
8.10	Some conclusions about FACE experiments	211
8.10.1	Will a high CO ₂ world favor C ₃ species over C ₄ species?	211
8.10.2	What factors tend to decrease plant responses to CO ₂ fertilization?	212
8.11	There are other effects of enhanced CO ₂ on plants apart from growth rate	212
8.12	CO ₂ fertilization and soils	213
8.13	CO ₂ fertilization effects across trophic levels	215
8.13.1	Looking for signs of a CO ₂ fertilization effect in agriculture	216
8.13.2	Looking for signs of a CO ₂ fertilization effect in natural plant communities	216
8.13.3	The changing seasonal amplitude of CO ₂	218
8.14	CO ₂ levels and stomata out in nature	219
8.15	Direct CO ₂ effects and the ecology of the past	219
8.15.1	Direct CO ₂ effects on longer geological timescales	221

8.15.2 Ancient moist climates or high CO ₂ effects?	222
8.16 Other direct CO ₂ effects: in the oceans	224
8.17 The future direct CO ₂ effect: a good or a bad thing for the natural world?	224
8.18 Conclusion: the limits to what we can know	225
Bibliography	227
Index	231

Preface

I had wanted to write something like this book for many years, but would probably never have dared to attempt it unless I had been asked to by Chris Hammond at Francis Taylor say. As it is, this has become a rewarding experience for me personally, something which has forced me to read literature that I would not otherwise have read, and to clarify things in my head that would have remained quibbled.

What I have not had to do here is provide an accessible textbook for university students, and a generalist source of current scientific information and opinion for both students and the interested lay reader. I have myself often found it frustrating that there have been no accessible syntheses on most of the subjects dealt with here, and I hope that this book will fill the gap.

My friends and colleagues have provided valuable comments, savings. These include: Sven Schwenmann, Anja Klotz, Alan Chivers, Peter Thomas, Peter York, Peter York, Peter York, Mary Killion, Charlie Zander, Ross Becher, Christine Klotz, and Roger Pickett. If I could not stop myself from writing to the end of the book after they had written their careful advice, and after careful editing, they have helped through all of it. As a result of my writing this, I am also very grateful to everyone who has generously given me permission to use their own photographs as illustrations in this book, and I have named each one in the photo captions. Lastly but not least, my wife, Mei-Ling Lee has provided the encouragement to show that what I have been writing is of interest to somebody, somewhere.

Thanks in particular to Ned Colby for providing the photo of a simulation storm, which is the cover of this book.

Jonathan Adams
Newark, New Jersey, 2009