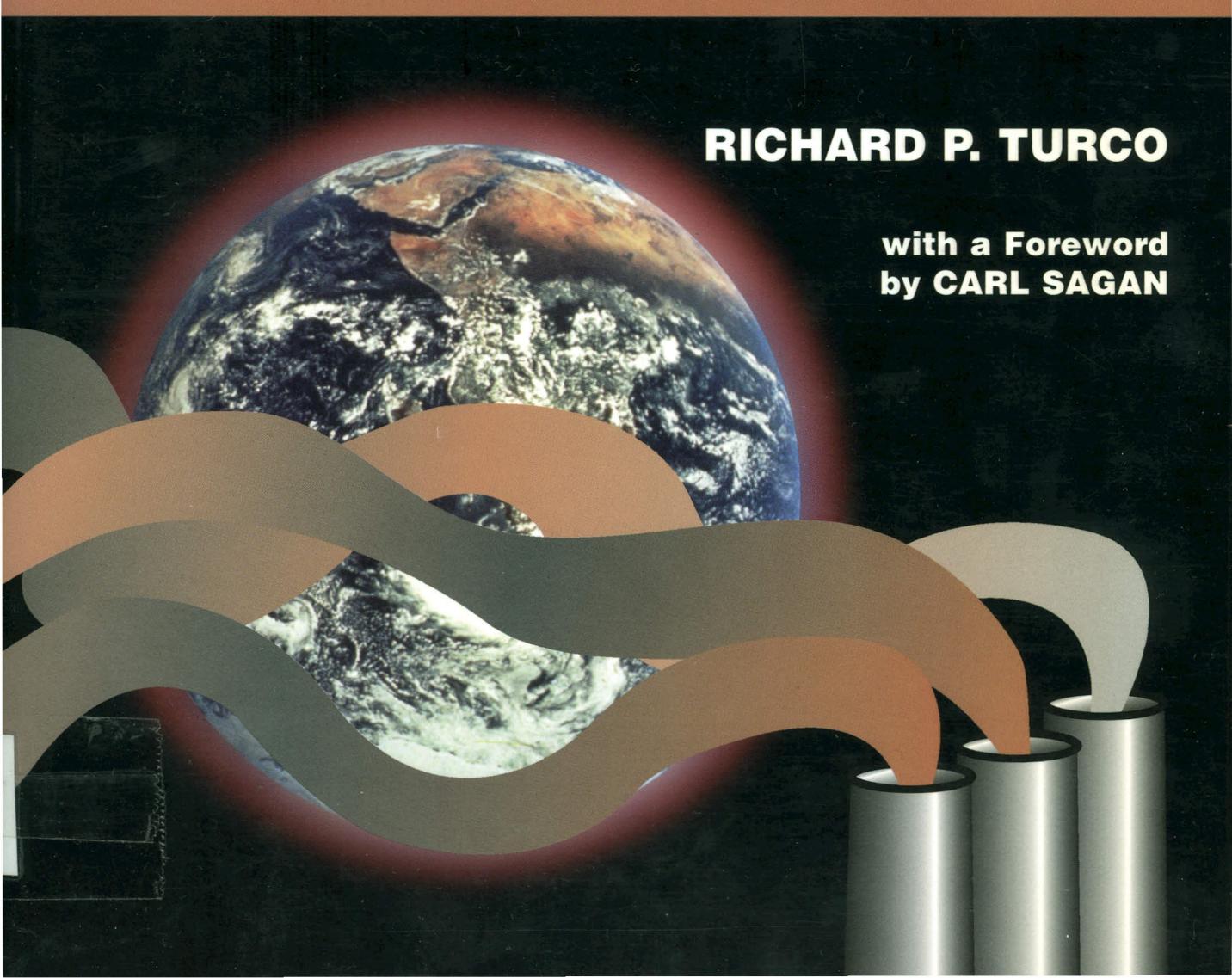


EARTH UNDER SIEGE

From Air Pollution to Global Change

RICHARD P. TURCO

**with a Foreword
by CARL SAGAN**



EARTH UNDER SIEGE

From Air Pollution to Global Change

Richard P. Turco

with a Foreword by Carl Sagan

323/3978

INSTITUT
FÜR METEOROLOGIE U. KLIMATOLOGIE
UNIVERSITÄT HANNOVER
HERRENHÄUSER STR. 2 - 30419 HANNOVER

Oxford New York
OXFORD UNIVERSITY PRESS
1997

Contents

<i>Foreword by Carl Sagan</i>	<i>xi</i>
<i>Preface</i>	<i>xiii</i>
1 Introduction	3
1.1 The Cronus Syndrome	3
1.2 On the Quality of Life	3
1.3 Global Change and Preservation	4
1.4 Methodology for Study	5
PART I FUNDAMENTALS	9
2 Air: The Medium of Change	11
2.1 What Is Air?	11
2.1.1 Sensing Air	12
2.1.2 The Basic Ingredients	13
2.1.3 The Basic Properties	14
2.2 A Short History of Discovery	20
2.2.1 The Air Revealed	21
2.2.2 The Mechanics of Air	24
2.3 The Structure of the Atmosphere	27
2.3.1 How Much Air Is There?	28
2.3.2 Temperature Profiles	29
2.3.3 The Stratification of the Atmosphere	31
2.4 Air in Motion	31
2.4.1 Local Winds and Weather	32
2.4.2 Global Wind Systems	33
Questions and Problems	36
3 Basic Physical and Chemical Principles	38
3.1 The Mechanical Behavior of Gases and Particles	38
3.1.1 Gas Laws and Hydrostatics	39
3.1.2 Particles in Suspension	46
3.1.3 Clouds and Precipitation	47
3.2 Radiation and Energy	48
3.2.1 Sunlight and Heat	51
3.2.2 Scattering and Absorption	55
3.2.3 Common Optical Effects	63
3.3 Chemistry and the Environment	68
3.3.1 Symbols and Terminology	68

3.3.2 Properties of Common Substances	71
3.3.3 The Mechanisms of Chemical Reactions	74
3.3.4 Basic Chemical Reactions	77
Questions	81
Problems	83
4 The Evolution of Earth	84
4.1 The Origin of the Earth	85
4.1.1 Early Evolutionary Phases	86
4.1.2 Box Models for Earth Reservoirs	88
4.1.3 The Prebiotic Atmosphere	91
4.2 The Coevolution of the Environment and Life	93
4.2.1 The Evolution of Life Processes	93
4.2.2 Ancient Organisms and Greenhouse Gases	96
4.2.3 Photosynthesis and the Ozone Layer	97
4.3 The Mass Extinction of Life	98
4.3.1 Fossil History	98
4.3.2 The Dinosaurs: A Lesson in Longevity	99
4.3.3 Goddess Gaia and Homeostasis	102
4.4 The Coevolution of Intelligence and Pollution	104
4.4.1 Population and Technology	104
Questions and Problems	106
PART II LOCAL AND REGIONAL POLLUTION ISSUES	109
5 Sources and Dispersion of Pollutants	111
5.1 The Source of the Problem	111
5.1.1 What to Call Pollutants?	111
5.1.2 Distributed and Point Sources	112
5.1.3 Size Scales of Dispersion	113
5.2 The Dispersion of Pollutants	113
5.2.1 Diffusion and Turbulence	113
5.2.2 Convection and Lofting	116
5.2.3 Advection and Long-Range Transport	117
5.3 Temperature Inversions	118
5.3.1 Temperatures in the Lower Atmosphere	119
5.3.2 Atmospheric Stability	122
5.3.3 Large-scale Inversions	125
5.4 Plumes of Pollution	128
5.4.1 Smokestack Plumes	129
5.4.2 Ground Plumes	130
5.4.3 Urban Heat Islands	131
5.5 Regional Dispersion of Pollutants	132
5.5.1 In Coastal Zones	132
5.5.2 Near Mountain Barriers	133
Questions	134
6 Smog: The Urban Syndrome	136
6.1 The History of Smog	136
6.1.1 Air Pollution and Poets	137

6.1.2	London Smog	138
6.1.3	Los Angeles Smog	139
6.2	Primary and Secondary Pollutants	140
6.2.1	The Basic Ingredients	140
6.2.2	Clean and Dirty Air	144
6.3	Smog Scenarios: A Typical Polluted Day	148
6.3.1	Carbon Monoxide	149
6.3.2	Nitrogen Dioxide	150
6.3.3	Ozone	153
6.4	Dissecting Smog	155
6.4.1	The Evolution of Smoggy Air	156
6.4.2	Trends in Air Pollution	158
6.5	Haze and Visibility	163
6.5.1	Total Suspended Particulate	165
6.5.2	Seeing Through Air	167
6.5.3	Acid Particles and Fog	172
6.6	Controlling Smog: Everyone's Job	174
6.6.1	Reducing Emissions of Primary Pollutants	174
6.6.2	Alternative Fuels	176
6.6.3	Lifestyles for Health and Survival	180
	Questions and Problems	181
7	Effects of Exposure to Pollution	183
7.1	How Pollutants Affect Health	184
7.1.1	The Discovery of Toxicity	184
7.1.2	The Physiology of Toxicity	187
7.2	The Toxic Effects of Air Pollutants	193
7.2.1	Common Ingredients of Smog	193
7.2.2	Eye Irritants	196
7.2.3	Organic Vapors	196
7.2.4	Problem Particles	198
7.2.5	Persistent Environmental Toxins	201
7.3	Radioactivity	203
7.3.1	Stability of the Elements	203
7.3.2	Sources of Radioactivity	206
7.3.3	The Physiological Effects of Radioactivity	210
7.4	Assessment of Health Risks	212
7.4.1	Defining the Threat	212
7.4.2	Risks and Benefits of Pollution	213
7.4.3	Box Models for Risk Assessment	215
7.4.4	Urban Smog: A Case Study	218
7.5	Limiting Risk	221
	Questions	221
	Problems	222
8	Indoor Air Pollution	223
8.1	What Are "Indoor" Air Pollutants?	223
8.1.1	The Special Character of Indoor Pollution	224
8.1.2	Indoor Pollution and the News	227

8.2	Radon: Mother and Daughters	227
8.2.1	Poison from the Earth	228
8.2.2	Radon Exposure and Its Effects	231
8.3	Formaldehyde	237
8.3.1	Embalmers' Fluid	237
8.3.2	Formaldehyde's Impacts on Health	241
8.4	Tobacco Smoke	242
8.4.1	Composition of Tobacco Smoke	244
8.4.2	Tobacco Smoke's Effects on Health	247
8.4.3	Smoke and Mirrors	250
8.5	Other Indoor Pollutants	252
8.5.1	Biogenic Pollutants	252
8.5.2	Indoor Water Pollution	253
8.6	Indoor Versus Outdoor Pollution	253
8.6.1	Is It Safe to Go Indoors?	254
8.6.2	Making Indoors Safe	256
	Questions	257
	Problems	258
9	Acid Rain	259
9.1	The Tainted Rain	259
9.2	Acidity and pH	261
9.2.1	The pH Scale	261
9.2.2	Acids in Water	264
9.2.3	Alkalinity: The Acid Buffer	266
9.3	Sources of Environmental Acids	267
9.3.1	How Acid Is Acid Rain?	268
9.3.2	Sulfur Oxides and Acid Rain	270
9.3.3	Nitrogen Oxides and Acid Rain	275
9.4	Acid Fog	277
9.5	The Costs of Excess Acidity	278
9.5.1	Dying Forests and Lakes	279
9.5.2	A Potpourri of Destruction	281
9.5.3	Health Implications	284
9.6	Controlling Acid Rain and Fog	285
	Questions	286
	Problems	287
PART III GLOBAL-SCALE POLLUTION ISSUES		289
	Carbon Dioxide and the Greenhouse Effect	289
	Ozone Depletion and the Ozone Hole	289
	Climate Change Caused by Nuclear War: Nuclear Winter	289
	The Relationship Between Population and Pollution	289
10	Global Biogeochemical Cycles	293
10.1	The Grand Chemical Cycles of Earth	293
10.1.1	Reservoirs in the Earth System	294
10.1.2	Simple Reservoir Models	295
10.2	Biogeochemical Cycles of the Primary Elements	298
10.2.1	Sulfur	298

10.2.2 Nitrogen	301
10.2.3 Oxygen	305
10.2.4 Carbon	307
10.3 The Hydrological Cycle	317
10.4 A Global Garbage Dump?	317
Questions and Problems	318
11 The Climate Machine	320
11.1 Weather and Climate	320
11.2 Energy from the Sun	321
11.2.1 Solar Illumination	322
11.2.2 The Four Seasons	323
11.3 The Temperature of Earth	324
11.3.1 Sunlight In, Earthglow Out	324
11.3.2 An Energy Balance Model	327
11.3.3 The Temperatures of the Planets	331
11.4 The Greenhouse Effect	332
11.4.1 Atmospheric Band Absorption	332
11.4.2 Radiation Emission from the Earth	335
11.4.3 Clouds and Radiation	339
11.4.4 The Greenhouse Energy Balance	342
11.5 Energy Reservoirs: The Climate Flywheel	344
11.5.1 Reservoirs for Heat	345
11.5.2 Ice: The Cool Reservoir	347
11.5.3 A Coupled Climate System	347
11.6 Causes of Climate Change	349
11.6.1 Climate Variability	350
11.6.2 Solar Variability: External Forcing	352
11.6.3 Ice Ages	354
11.6.4 Volcanic Eruptions	355
11.6.5 The Albedo Effect	358
11.7 The Vulnerability of Life to a Changing Climate	359
11.7.1 Modern Society and Climate	359
11.7.2 Do We Need Climate Insurance?	361
Questions and Problems	363
12 Greenhouse Warming	365
12.1 Greenhouse Gases	365
12.1.1 The Greenhouse Culprits: A Rogue's Gallery	365
12.1.2 Water Vapor: Innocent Bystander or Good Samaritan?	366
12.2 Carbon Dioxide	368
12.2.1 Increasing CO ₂ : What Is the Cause?	368
12.2.2 The Problem with Energy Addiction	370
12.2.3 A Global Reservoir Perspective	372
12.3 Other Greenhouse Gases	375
12.3.1 Methane	375
12.3.2 Nitrous Oxide	377
12.3.3 Chlorofluorocarbons	378
12.3.4 Ozone	380
12.4 The Warming Effect of Greenhouse Gases	381

viii	Earth Under Siege	
12.4.1	Climate History and the Greenhouse Effect	381
12.4.2	Recent Temperature Trends	384
12.4.3	Forecasts of Greenhouse Warming	386
12.4.4	Uncertainty Is the Future	393
12.5	Solutions?	397
12.5.1	Recyclable Fuels	398
12.5.2	Alternative Energy Sources	399
12.5.3	Climate Correction: Endangering the Environment	402
	Questions	404
	Problems	405
13	The Stratospheric Ozone Layer	407
13.1	The Ozone Shield	407
13.2	The Formation and Destruction of Ozone	407
13.2.1	The Photochemistry of Ozone	408
13.2.2	The Destruction of Catalytic Ozone	410
13.3	The Distribution of Ozone in the Atmosphere	410
13.3.1	Dobson Units: Ozone Overhead	411
13.3.2	How Much Ozone Is There?	413
13.4	Ozone and Ultraviolet Radiation	414
13.4.1	Regions of the Ultraviolet Spectrum	415
13.4.2	Health Effects of UV-B Radiation	416
13.4.3	Environmental Effects of UV-B Radiation	421
13.5	Threats Against Ozone	422
13.5.1	A Litany of Threats	422
13.5.2	Chlorine	422
13.5.3	Nitrogen Oxides and Ozone Change	429
13.5.4	Bromine and the Halons	432
13.6	Forecasts of Global Ozone Depletion	433
13.6.1	Scenarios and Projections	433
13.6.2	Signature of the Culprit	436
13.7	The Ozone Hole	437
13.7.1	Discovery	437
13.7.2	The Polar Vortex	438
13.7.3	Polar Stratospheric Clouds	440
13.7.4	Ozone Depletion: The Hole Story	443
13.7.5	A Global Ozone Disaster?	445
13.8	Solutions and Actions	447
13.8.1	The Montreal Protocol	447
13.8.2	Saving the Earth's Ozone Layer	449
	Questions and Problems	450
14	Global Environmental Engineering	452
14.1	What Is Global Environmental Engineering?	452
14.1.1	Living Thermostats: Natural Compensation	452
14.1.2	Planetary Engineering	455
14.2	Technological Traps	457
14.2.1	Nuclear Winter	457
14.2.2	Carbon Dioxide	461
14.2.3	Chlorofluorocarbons	463

14.3 Technological Cures	463
14.3.1 Preventing Armageddon	464
14.3.2 Cooling Down the Greenhouse	465
14.3.3 Fixing the Ozone Shield	476
14.4 A Rational Approach to Environmental Management	483
Questions	486
Problems	487
Appendix A Scientific Notation, Units, and Constants	489
A.1 Scientific Notation	489
Applications of Scientific Notation	489
Large and Small Numbers	490
Using Mixing Ratios	490
A.2 The Metric System: Units and Conversions	492
Common Units of Measure	493
Manipulation of Dimensions and Units	494
A.3 Physical and Mathematical Constants	495
Physical Constants (and Their Common Symbols)	495
Mathematical Constants	496
A.4 Mathematical Operations	497
Squares and Square Roots	497
Higher Powers	497
Exponentials and Logarithms	497
Algebraic Equations	498
Inequalities	499
Appendix B Demonstrations of Common Natural Phenomena	500
Demonstration 1: Light Scattering by Small Particles	500
Background	500
Experimental Procedure	501
Demonstration 2: Gas-to-Particle Conversion in Smog	501
Background	501
Experimental Procedure	501
Demonstration 3: Atmospheric Pressure and Water Vapor Condensation	502
Background	502
Experimental Procedure	503
Demonstration 4: Acid Rain Formation	503
Background	503
Experimental Procedure	504
Appendix C Radiation Nomenclature	507
<i>Index</i>	509