

Contents

List of Contributors *XV*

Preface *XIX*

Foreword *XXI*

Acknowledgments *XXIII*

1	Primary and Secondary Sources of Atmospheric Aerosol	1
	<i>Claudio Tomasi and Angelo Lupi</i>	
1.1	Introduction	1
1.2	A General Classification of Aerosol Sources	6
1.3	Primary Aerosols of Natural Origin	7
1.3.1	Sea-Salt Particles	8
1.3.2	Mineral Dust	13
1.3.3	Biogenic Aerosols	20
1.3.4	Forest Fire Smoke	23
1.3.5	Volcanic Dust in the Troposphere	27
1.3.6	Cosmic Dust	30
1.4	Secondary Aerosols of Natural Origin	31
1.4.1	Natural Sulfate Particles from Tropospheric SO ₂ and Sulfur Compounds	32
1.4.2	Natural Nitrate Particles from Tropospheric Nitrogen Oxides	37
1.4.3	Organic Aerosols from Biogenic Volatile Organic Compounds	41
1.4.4	Sulfate Particles from Marine and Volcanic SO ₂ Formed in the Stratosphere	42
1.5	Primary Anthropogenic Aerosols	48
1.5.1	Industrial Dust	50
1.5.2	Anthropogenic Aerosols from Fossil Fuel Combustion and Carbonaceous (Soot) Particles	51
1.5.3	Anthropogenic Aerosols from Waste and Biomass Burning	58
1.6	Secondary Anthropogenic Aerosols	59
1.6.1	Secondary Particles from SO ₂	60
1.6.2	Secondary Particles from NO _x	64
1.6.3	Secondary Organic Aerosols	68

1.7	Concluding Remarks on the Global Annual Emission Fluxes of Natural and Anthropogenic Aerosol Mass	70
	Abbreviations	75
	List of Symbols	75
	References	76
2	Aerosol Nucleation in the Terrestrial Atmosphere	87
	<i>Karine Sellegri and Julien Boulon</i>	
2.1	Introduction	87
2.2	Theoretical Basis of Nucleation and Growth of New Particles in the Atmosphere	88
2.2.1	Introduction to Nucleation Theories Useful in Atmospheric Sciences	88
2.2.1.1	The Unary System Model	89
2.2.1.2	The $\text{H}_2\text{SO}_4\text{--H}_2\text{O}$ Binary System	91
2.2.1.3	The $\text{H}_2\text{SO}_4\text{--NH}_3\text{--H}_2\text{O}$ Ternary System	93
2.2.1.4	The Role of Amines	93
2.2.1.5	The Ion-Induced Nucleation	94
2.2.2	The Growth of New Particles	95
2.2.2.1	The Condensation Process	95
2.3	Observation and Detection Tools	97
2.3.1	Detection Tools	98
2.3.1.1	Physical Characterization	98
2.3.1.2	Chemical Characterization	99
2.3.2	Metrics for Characterizing New Particle Formation Events	100
2.3.3	Occurrence of New Particle Formation Events in the Troposphere	102
2.3.3.1	Pristine and Polluted Continental Boundary Layer	102
2.3.3.2	Coastal and Marine Boundary Layer Sites	103
2.3.3.3	High-Altitude Environments and Free Troposphere	103
2.4	Precursor Candidates for Nucleation and Early Growth from Observations	104
2.4.1	Continental Planetary Boundary Layer	104
2.4.2	Marine Planetary Boundary Layer	104
2.5	Parameterizations and Chamber Experiments	105
2.6	Importance of Nucleation for the Production of Aerosols and CCN at the Global Scale	107
2.7	Conclusions	108
	Abbreviations	109
	List of Symbols	110
	References	110
3	Coagulation, Condensation, Dry and Wet Deposition, and Cloud Droplet Formation in the Atmospheric Aerosol Life Cycle	115
	<i>Claudio Tomasi and Angelo Lupi</i>	
3.1	Introduction	115

3.2	Physical Growth Processes	120
3.2.1	Brownian Coagulation	121
3.2.2	Growth by Condensation of Gases onto Preexisting Particles	128
3.2.3	The Kelvin Effect	130
3.2.4	Hygroscopic Growth of Particles by Water Vapor Condensation	133
3.3	Aerosol Removal Processes	139
3.3.1	Dry Deposition of Aerosol Particles	141
3.3.2	Wet Deposition of Aerosol Particles	144
3.3.2.1	In-Cloud Scavenging (Rainout)	145
3.3.2.2	Interstitial Aerosol Scavenging by Cloud Droplets	147
3.3.2.3	Precipitation Scavenging	149
3.3.2.4	Wet Deposition in Fogs	157
3.3.2.5	Nucleation of Ice Particles	157
3.4	Formation of Cloud Particles	161
3.4.1	Water Vapor Condensation	162
3.4.2	The Köhler Theory	163
3.4.3	The Cloud Condensation Nuclei	169
3.5	Concluding Remarks	170
	Abbreviations	175
	List of Symbols	175
	References	180
4	Chemical Composition of Aerosols of Different Origin	183
	<i>Stefania Gilardoni and Sandro Fuzzi</i>	
4.1	Introduction	183
4.2	Global Distribution and Climatology of the Main Aerosol Chemical Constituents	184
4.2.1	Definition of Primary and Secondary Inorganic and Organic Aerosol Compounds	184
4.2.2	Aerosol Global Budgets	186
4.2.2.1	Organic Aerosol	186
4.2.2.2	Black Carbon Aerosol	187
4.2.2.3	Sulfur Aerosol	188
4.2.2.4	Nitrogen Aerosol Species	189
4.2.2.5	Dust Aerosol	191
4.2.3	Main Regional Differences and Seasonal Variations of Aerosol Chemical Composition	192
4.2.3.1	Urban Aerosol	192
4.2.3.2	Rural Aerosol	193
4.2.3.3	Continental Regional Background Aerosol	194
4.2.3.4	Marine Background Aerosol	195
4.3	Size Distributions of Aerosol Chemical Compounds	196
4.3.1	Aerosol Size-Resolved Chemical Composition in Polluted Areas	196

4.3.1.1	Secondary Inorganic Aerosol (Ammonium Sulfate and Nitrate)	197
4.3.1.2	Organic Aerosol	197
4.3.1.3	Black Carbon	198
4.3.1.4	Dust	200
4.3.2	Aerosol Size-Resolved Chemical Composition in Unperturbed Environments	200
4.3.2.1	Rain Forest	200
4.3.2.2	High Altitude Mountain Regions	200
4.3.2.3	Polar Regions	202
4.3.3	Long-Term Changes of Aerosol Chemical Components	203
4.4	Issues Related to Aerosol Chemical Composition	205
4.4.1	Characterization of the Aerosol Carbonaceous Fraction	205
4.4.1.1	Soot: BC or EC	205
4.4.1.2	Organic Aerosol	207
4.4.2	Sources of BC and OA	209
4.4.2.1	Black Carbon	209
4.4.2.2	Organic Aerosol	211
4.4.3	Effect of Organic and Inorganic Chemical Composition on Aerosol Activity as Cloud Condensation Nuclei and Ice Nuclei	213
4.4.3.1	Cloud Condensation Nuclei	213
4.4.3.2	Ice Nuclei	214
	Abbreviations	216
	List of Symbols	217
	References	218
5	Aerosol Optics	223
	<i>Alexander A. Kokhanovsky</i>	
5.1	Introduction	223
5.2	Absorption	224
5.3	Scattering	229
5.4	Polarization	234
5.5	Extinction	237
5.6	Radiative Transfer	239
5.7	Image Transfer	242
	Abbreviations	244
	List of Symbols	244
	References	245
6	Aerosol Models	247
	<i>Claudio Tomasi, Mauro Mazzola, Christian Lanconelli, and Angelo Lupi</i>	
6.1	Introduction	247
6.2	Modeling of the Optical and Microphysical Characteristics of Atmospheric Aerosol	249
6.2.1	The 6S Code Aerosol Extinction Models	254

6.2.1.1	The Four 6S Basic Aerosol Components	254
6.2.1.2	The Three 6S Aerosol Models	258
6.2.2	The 6S Additional Aerosol Models	262
6.2.3	The 6S Modified (M-Type) Aerosol Models	271
6.2.4	The OPAC Aerosol Models	277
6.2.5	The Aerosol Models of Shettle and Fenn (1979)	288
6.2.6	The Seven Additional Aerosol Models of Tomasi <i>et al.</i> (2013)	295
6.2.7	The Polar Aerosol Models	304
6.3	General Remarks on the Aerosol Particle Number, Surface, and Volume Size-Distribution Functions	306
6.3.1	The Aerosol Particle Number Size-Distribution Function	310
6.3.2	The Aerosol Surface, Volume, and Mass Size Distributions	314
6.4	Size-Distribution Characteristics of Various Aerosol Types	317
6.4.1	Remote Continental Aerosols	317
6.4.2	Free Tropospheric Aerosols	319
6.4.3	Rural-Continental Aerosols	319
6.4.4	Continental-Polluted Aerosols	322
6.4.5	Maritime Clean Aerosols	322
6.4.6	Maritime-Polluted Aerosols	324
6.4.7	Desert Dust	324
6.4.8	Biomass Burning Aerosols	326
6.4.9	Urban Aerosols	326
6.4.10	Polar Arctic Aerosols	328
6.4.11	Polar Antarctic Aerosols	329
6.4.12	Stratospheric Volcanic Aerosols	331
6.5	Concluding Remarks	332
	Abbreviations	333
	List of Symbols	334
	References	337
7	Remote Sensing of Atmospheric Aerosol	341
	<i>Alexander A. Kokhanovsky, Claudio Tomasi, Boyan H. Petkov, Christian Lanconelli, Maurizio Busetto, Mauro Mazzola, Angelo Lupi, and Kwon H. Lee</i>	
7.1	Introduction	341
7.2	Ground-Based Aerosol Remote Sensing Measurements	342
7.2.1	The Multispectral Sun-Photometry Method	345
7.2.1.1	Calibration of a Sun Photometer Using the Langley Plot Method	346
7.2.1.2	Determination of Aerosol Optical Thickness	348
7.2.1.3	Determination of Aerosol Optical Parameters from Sun-Photometer Measurements	360
7.2.1.4	Relationship between the Fine Particle Fraction and Ångström Wavelength Exponent	370

7.2.2	Measurements of Volume Extinction, Scattering, and Absorption Coefficients at Ground Level Using Nephelometer and PSAP Techniques	373
7.2.3	Vertical Profiles of Backscatter and Extinction Coefficients from LIDAR Measurements	375
7.2.4	Measurements of the Aerosol Size Distribution Using an Optical Particle Counter	378
7.3	Airborne Remote Sensing Measurements of Aerosol Optical Properties	380
7.3.1	Main Results Derived from the Second Airborne Arctic Stratospheric Expedition (AASE-II) Measurements	385
7.3.2	Airborne Remote Sensing Measurements during the Army LIDAR Verification Experiment (ALIVE)	386
7.3.3	Airborne Measurements Performed during the Sulfate Clouds and Radiation–Atlantic (SCAR-A) Experiment	386
7.3.4	Airborne Measurements Conducted during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX)	387
7.3.5	The Aerosol Characterization Experiment 2 (ACE-2) Airborne Remote Sensing Measurements	388
7.3.6	Airborne Remote Sensing Measurements during the Puerto Rico Dust Experiment (PRIDE)	391
7.3.7	The ARCTAS/ARCPAC Airborne Remote Sensing Measurements in the Western Arctic	392
7.3.8	The Airborne Measurements Conducted during the Pan-Arctic Measurements and Arctic Regional Climate Model Intercomparison Project (PAM-ARCMIP)	399
7.4	Satellite-Borne Aerosol Remote Sensing Measurements	403
7.4.1	Satellite Instrumentation	403
7.4.2	Methods	411
7.4.2.1	The Algorithms Based on the Single-View Spectral Observations	411
7.4.2.2	Double-View Spectral Observations	412
7.4.2.3	Multiview Spectral Observations	413
7.4.2.4	Multiview Spectral and Polarimetric Observations	413
7.4.2.5	Retrievals over Ocean Using Multiangle Polarimetric Observations	414
7.4.2.6	Retrievals over Land	414
7.4.2.7	Aerosol Retrieval Using an Artificial Neural Network Technique	414
7.4.3	Examples of Aerosol Retrievals	415
7.4.3.1	Global View of Aerosol Distribution from Passive Sensor	415
7.4.3.2	Aerosol Retrieval from Different Sensors and Retrieval Algorithms	416
7.4.3.3	Time-Resolved Observation from Geostationary Platform	419

7.4.3.4	Atmospheric Anatomy from the Active Sensing Platform	421
	Abbreviations	422
	List of Symbols	423
	References	427
8	Aerosol and Climate Change: Direct and Indirect Aerosol Effects on Climate	437
	<i>Claudio Tomasi, Christian Lanconelli, Mauro Mazzola, and Angelo Lupi</i>	
8.1	Introduction	437
8.2	The Instantaneous DARF Effects at the ToA and BoA Levels and in the Atmosphere	439
8.2.1	The Spectral Characteristics of Solar Radiation	439
8.2.2	Vertical Features of Aerosol Volume Extinction Coefficient	443
8.2.3	Aerosol Extinction Models and Optical Characteristics	444
8.2.4	Modeling the Underlying Surface Reflectance Characteristics	447
8.2.5	Calculations of Instantaneous DARF Terms at the ToA and BoA Levels and within the Atmosphere	459
8.2.6	Dependence Features of Instantaneous DARF Terms on Aerosol Optical Parameters and Surface Reflectance	463
8.2.6.1	Dependence of Instantaneous DARF on Aerosol Optical Thickness	464
8.2.6.2	Dependence of Instantaneous DARF on Aerosol Single Scattering Albedo	467
8.2.6.3	Dependence of Instantaneous DARF on Underlying Surface Albedo	471
8.2.6.4	Dependence of Instantaneous DARF on Solar Zenith Angle	474
8.3	The Diurnally Average DARF Induced by Various Aerosol Types over Ocean and Land Surfaces	476
8.3.1	Description of the Calculation Method Based on the Field Measurements of Aerosol Optical Parameters	478
8.3.2	Calculations of the Diurnally Average DARF Terms and Efficiency Parameters for Eleven Aerosol Types	498
8.3.2.1	Remote Continental Aerosols	498
8.3.2.2	Rural-Continental Aerosols	500
8.3.2.3	Free Tropospheric Aerosols	502
8.3.2.4	Continental-Polluted Aerosols	504
8.3.2.5	Maritime Clean Aerosols	506
8.3.2.6	Maritime-Continental Aerosols	508
8.3.2.7	Desert Dust	512
8.3.2.8	Biomass Burning Aerosols	516
8.3.2.9	Urban and Industrial Aerosols	519
8.3.2.10	Polar Aerosols	522
8.3.2.11	Stratospheric Volcanic Aerosols	525
8.4	Variations of DARF Efficiency as a Function of Aerosol Single Scattering Albedo	525

8.5	Concluding Remarks on the DARF Effects over the Global Scale	529
8.6	On the Indirect Aerosol Effects Acting in the Earth's Climate System	531
	Abbreviations	537
	List of Symbols	538
	References	541
9	Aerosol and Air Quality	553
	<i>Sandro Fuzzi, Stefania Gilardoni, Alexander A. Kokhanovsky, Walter Di Nicolantonio, Sonoyo Mukai, Itaru Sano, Makiko Nakata, Claudio Tomasi, and Christian Lanconelli</i>	
9.1	Introduction	553
9.1.1	Aerosol Air Pollution	553
9.1.2	Aerosol Sources and Size Distribution in Relation to Human Health Effects	553
9.1.3	Aerosol Chemical Composition and Health Effects	555
9.1.4	Atmospheric Aerosols, Air Pollution, and Climate Change	557
9.1.5	Aerosol Load in Different Areas of the World	558
9.2	Aerosol Load as Derived from Satellite-Based Measurements	560
9.2.1	VIS/NIR/SWIR Multispectral Satellite Observations for Evaluating PM Concentrations: An Example over the Northern Italy Area	560
9.2.1.1	MODIS-Based PM Concentration Estimates at the Surface	561
9.2.1.2	Data Set and Results	563
9.2.1.3	Satellite PM Multiannual Monitoring: Looking for Compliance to European Air Quality Directive	566
9.2.2	PM Estimations over Osaka (Japan) Based on Satellite Observations	569
9.2.2.1	Introduction	569
9.2.2.2	Aerosol Remote Sensing	571
9.2.2.3	Estimation of PM from Satellite-Based AOT	574
9.3	Characterization of Mass Concentration and Optical Properties of Desert Dust in Different Areas of the Earth	577
9.3.1	Dust Storms in the Southwestern United States	578
9.3.2	Saharan Dust Transport over the Southeastern United States and the Caribbean Region	579
9.3.3	Saharan Dust Transport over the Tropical Atlantic Ocean and the Western Coast of Africa	580
9.3.4	Saharan Dust Transport Toward Southern Europe	581
9.3.5	Saharan Dust Transport Toward the Middle Eastern and the Persian Gulf	584
9.3.6	Asian Dust Transport Over Central Asia and China	584
9.3.7	Asian Dust Transport Over Korea and Japan	588
9.3.8	Desert Dust Transport Over Oceanic Areas	589

Abbreviations	589
List of Symbols	590
References	591

10 Impact of the Airborne Particulate Matter on the Human Health 597

Marina Camatini, Maurizio Gualtieri, and Giulio Sancini

10.1	Introduction	597
10.2	Epidemiological Evidences	600
10.2.1	Exacerbation of Lung Diseases	602
10.2.2	Effects on the Cardiovascular System	603
10.2.3	Life Expectancy and PM Concentration	606
10.3	Toxicological Evidences	609
10.3.1	Particle Dosimetry, Particle Deposition, and Real Exposure	609
10.3.2	<i>In Vivo</i> Evidences	612
10.3.2.1	Lung Inflammation	613
10.3.2.2	Cardiovascular Damages	615
10.3.2.3	Brain and Other Target Organs	618
10.3.3	<i>In Vitro</i> Evidences	622
10.3.3.1	Inflammatory Response	622
10.3.3.2	Oxidative Stress	624
10.3.3.3	DNA Damage	626
10.3.3.4	Cell Death	627
10.4	Mechanism of Effects	630
10.4.1	The Inflammatory Paradigm	630
10.4.2	The Reactive Oxygen Species	632
10.4.3	Translocation of Particles: If Yes Then Where	634
10.4.4	Dimension versus Composition: Two Heads of the “PM Hydra”	636
10.5	Conclusions	637
	Abbreviations	638
	List of Symbols	639
	References	639

11 Aerosol Impact on Cultural Heritage: Deterioration Processes and Strategies for Preventive Conservation 645

Alessandra Bonazza, Paola De Nuntiis, Paolo Mandrioli, and Cristina Sabbioni

11.1	Introduction	645
11.2	Monitoring for Cultural Heritage Conservation	645
11.3	Damage and Black Crusts Formation on Building Materials	652
11.3.1	Damage to Carbonate Stone	653
11.3.2	Damage to Silicate Stone	655
11.3.3	Anthropogenic Aerosol in Crusts	656
11.3.4	Organic and Elemental Carbon	657
11.3.5	Damage to Coastal Areas	658
11.4	Bioaerosol Effects on Cultural Heritage	659

11.5	Guidelines for the Preventive Conservation of Cultural Heritage in Urban Areas	664
	Abbreviations	665
	List of Symbols	665
	References	666
	Index	671