Pref	ace	page	xiii
	nowledgments		xiv
1	Introduction and the last the		1
	1.1 Brief history of meteorological sciences		1
	1.2 Brief history of air-pollution science		5
	1.3 The merging of air-pollution and meteorological sciences		6
	1.4 Weather, climate, and air pollution		6
	1.5 Scales of motion		8
	1.6 Atmospheric processes		8
2	Atmospheric structure, composition, and thermodynamics		12
202	2.1 Pressure, density, and composition		12
	2.2 Temperature structure		18
	2.3 Equation of state		28
	2.4 Changes of pressure with altitude		34
	2.5 Water in the atmosphere		37
	2.6 First law of thermodynamics		47
	2.7 Summary		57
	2.8 Problems		58
	2.9 Computer programming practice		60
3	The continuity and thermodynamic energy equations		61
	3.1 Definitions		61
	3.2 Continuity equations		65
	3.3 Expanded continuity equations		68
	3.4 Thermodynamic energy equation		78
	3.5 Summary		80
	3.6 Problems		80
	3.7 Computer programming practice		81
4	The momentum equation in Cartesian and spherical		
	coordinates		82
	4.1 Horizontal coordinate systems		82
	4.2 Newton's second law of motion		87
	4.3 Applications of the momentum equation		111
	4.4 Summary		135

	4.5	Problems	136
	4.6	Computer programming practice	137
5	Vertic	cal-coordinate conversions	138
	5.1	Hydrostatic and nonhydrostatic models	138
	5.2	Altitude coordinate	143
	5.3	Pressure coordinate	143
	5.4	Sigma-pressure coordinate	151
	5.5	Sigma-altitude coordinate	160
	5.6	Summary	167
	5.7	Problems	167
	5.8	Computer programming practice	168
6	Num	erical solutions to partial differential equations	169
	6.1		169
	6.2	Operator splitting	170
	6.3		171
	6.4		172
	6.5		192
	6.6	Finite-volume methods	199
	6.7	Advection schemes used in air-quality models	199
	6.8	Summary	202
	6.9	Problems	202
	6.10	Computer programming practice	203
7	Finite	e-differencing the equations of atmospheric dynamics	204
	7.1	Vertical model grid	204
	7.2		208
	7.3	The species continuity equation	211
	7.4	The thermodynamic energy equation	213
	7.5	The horizontal momentum equations	214
	7.6	The hydrostatic equation	221
	7.7	Order of calculations	222
	7.8	Time-stepping schemes	222
	7.9	Summary	224
	7.10	Problems	224
	7.11	Computer programming practice	225
	7.12	Modeling project	225
8	Boun	dary-layer and surface processes	228
	8.1	Turbulent fluxes of momentum, energy,	
		and moisture	228
	8.2	Friction wind speed	230
	8.3	Surface roughness lengths	231
	8.4	Parameterizations of kinematic turbulent fluxes	235
	8.5	Eddy diffusion above the surface layer	250
	8.6	Ground surface temperature and soil moisture	254

	8.7	Summary Casamina OLCA	271
442	8.8	Problems 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	271
	8.9	Computer programming practice	272
9	Radia	tive energy transfer	273
446	9.1	Energy transfer processes	273
	9.2	Electromagnetic spectrum	275
	9.3	Light processes	283
	9.4	Absorption and scattering by gases and particles	290
	9.5	Visibility	313
	9.6	Optical depth	316
	9.7	Solar zenith angle	317
	9.8	The radiative transfer equation	320
	9.9	Summary	334
	9.10	Problems	334
	9.11	Computer programming practice	335
10	Gas-p	phase species, chemical reactions, and reaction rates	336
	10.1	Atmospheric gases and their molecular structures	336
	10.2	Chemical reactions and photoprocesses	342
	10.3	Reaction rates	344
	10.4	Reaction rate coefficients	346
	10.5	Sets of reactions	351
	10.6	Stiff systems	353
	10.7	Summary	355
	10.8	Problems	355
	10.9	Computer programming practice	356
11	Urba	n, free-tropospheric, and stratospheric chemistry	357
	11.1	Free-tropospheric photochemistry	357
	11.2	Urban photochemistry	375
	11.3	Stratospheric photochemistry	393
	11.4	Summary	415
	11.5	Problems	416
	11.6	Problems Computer programming practice	417
12	Meth	ods of solving chemical ordinary differential equations	
	12.1	Characteristics of chemical ODEs	418
	12.2	Analytical solutions to ODEs	421
	12.3	Taylor series solution to ODEs	421
	12.4	Forward Euler solution to ODEs	422
	12.5	Backward Euler solution to ODEs	424
	12.6	Simple exponential and quasi-steady-state	
		solutions to ODEs	426
	12.7	Multistep implicit-explicit (MIE) solution to ODEs	
	12.8	Gear's solution to ODEs	432
	12.9	Family solution to ODEs	439

	12.10	Summary		442
	12.11	Problems		442
	12.12	Computer programming practice		443
		Modeling project		444
13	Partic	le components, size distributions, and size structures		446
	13.1	Introduction to particles		446
	13.2	Aerosol, fog, and cloud composition		447
	13.3	Discrete size distributions		449
	13.4	Continuous size distributions		454
	13.5	Evolution of size distributions over time		462
	13.6	Summary Signs dains a slock		467
	13.7	Problems		468
	13.8	Computer programming practice		468
14	Aeros	ol emission and nucleation		470
	14.1	Aerosol emission		470
	14.2	Nucleation		484
	14.3	Summary		492
	14.4	Problems		493
	14.5	Computer programming practice	18/01	493
15	Coagu	llation also coefficients		494
	15.1	Implicit coagulation		494
	15.2	Semiimplicit Coagulation		496
	15.3	Comparison with analytical solutions		498
	15.4	Coagulation among multiple particle distributions		500
	15.5	Particle flow regimes		505
	15.6	Coagulation kernel		508
	15.7	Summary		522
	15.8	Problems		523
	15.9	Computer programming practice		523
16	Conde	ensation, evaporation, deposition, and sublimation		525
	16.1	Fluxes to and from a single drop		525
	16.2	Corrections to growth parameters		528
	16.3	Fluxes to a particle with multiple components		540
	16.4	Fluxes to a population of particles		540
	16.5	Solutions to growth equations		542
	16.6	Solving homogeneous nucleation with		
		condensation		545
	16.7	Effects of condensation on coagulation		547
	16.8	Ice crystal growth		548
	16.9	Summary Summar		550
		Problems		550
	16.11	Computer programming practice		551

17	Chem	ical equilibrium and dissolution processes	553
672	17.1	Definitions was assistable above to moduse to wall assent A. A.	553
	17.2	Equilibrium reactions	554
	17.3	Equilibrium relation and coefficients	558
	17.4	Forms of equilibrium-coefficient equations	562
	17.5	Mean binary solute activity coefficients	565
	17.6	Temperature dependence of binary solute activity coefficients	567
	17.7	Mean mixed solute activity coefficients	568
	17.8	The water equation	570
	17.9	Solid formation and deliquescence relative	
		humidity	574
	17.10	Example equilibrium problem	575
	17.11	Mass-flux iteration method	577
	17.12	Analytical equilibrium iteration method	579
	17.13	Equilibrium solver results	582
	17.14	Nonequilibrium between gases and particles	583
	17.15	Summary	594
	17.16	Problems anoisasymos suissas 18	596
	17.17	Computer programming practice	596
18	Cloud	thermodynamics and dynamics	598
	18.1	Fog and cloud types and formation mechanisms	598
	18.2	Moist adiabatic and pseudoadiabatic processes	602
	18.3	Cloud development by free convection	606
	18.4	Entrainment	608
	18.5	Vertical momentum equation in a cloud	610
	18.6	Convective available potential energy	612
	18.7	Cumulus parameterizations	612
	18.8	Cloud microphysics	614
	18.9	Summary	642
	18.10	Problems	643
	18.11	Computer programming practice	643
19	Irreve	rsible aqueous chemistry	645
	19.1	Significance of aqueous chemical reactions	645
	19.2	Mechanisms of converting S(IV) to S(VI)	646
	19.3	Diffusion within a drop	652
	19.4	Solving growth and aqueous chemical ODEs	654
	19.5	Summary	659
	19.6	Problems	659
	19.7	Computer programming practice	660
20	Sedim	entation, dry deposition, and air-sea exchange	661
	20.1	Sedimentation	661
	20.2	Dry deposition	665

	20.3 20.4 20.5	Dry deposition and sedimentation calculations Air–sea flux of carbon dioxide and other gases Summary		670 672 679
	20.6 20.7	Problems Computer programming practice		679 679
21	Mode 21.1 21.2 21.3 21.4 21.5	I design, application, and testing Steps in model formulation Example model simulations Summary Problems Computer programming practice		681 700 707 707 707
App	endix A	A Conversions and constants		709
445	A.1	Distance conversions		709
	A.2	Volume conversions		709
583	A.3	Mass conversions		709
	A.4	Temperature conversions		710
	A.5	Force conversions		710
	A.6	Pressure conversions		710
	A.7	Energy conversions		710
	A.8	Power conversions		710
	A.9	Speed conversions		710
	A.10	Constants		711
App	endix I			714
11PP	B.1	Standard atmospheric variables versus altitude		714
	B.2	Solar irradiance at the top of the atmosphere		715
	B.3	Chemical symbols and structures of gases		716
	B.4	Gas-phase reactions		728
	B.5	Chemicals involved in equilibrium and aqueous reactions		738
	B.6	Thermodynamic data		740
	B.7	Equilibrium reactions and rate coefficients		741
	B.8	Irreversible aqueous reactions		743
	B.9	Solute activity coefficient data		746
	B.10	Water activity data		748
	B.11	Surface resistance data		749
	B.12	More surface resistance data		751
Refe	rences	212020 Sarrace resistance data		752
Inde				784
				101