

Index

a

- absorptance 90, 106, 118
- absorption
 - atmosphere 30, 186, 190, 191, 193, 197
 - band strength, molecular 170
 - coefficient 78, 90
 - cross section 65, 69, 77
 - earth 4, 26, 30, 31, 33, 35, 197
 - inhomogeneous path 174, 176, 178
 - line strength 163
 - overlapping bands, molecular 182
 - overlapping lines 171
 - particle 121, 136
 - radiative transfer equation 79, 81
 - spectra, molecular 28
 - strong, pressure-broadened line limit 166, 171, 193, 205, 206
 - surface 30, 197
 - weak line limit 164, 166, 168, 170, 172, 175, 191, 206
- absorptivity 6, 90
- actinic flux 115
- adding layers
 - adding-doubling method 138
 - Eddington approximation 121
- adding-doubling method 138
- adiabatic lapse rate 22
- aerosol 18
 - continental, composition 76
 - direct radiative forcing 199
 - extinction cross section, example 69
 - indirect radiative forcing 200
 - infrared scattering and absorption 80
 - optical depth, example 69
 - reflectance, δ -Eddington approximation 133, 136
 - reflectance, Eddington approximation 120, 133, 136
 - reflectivity, single scattering approximation 136
 - scattering phase function, example 75
 - upward scattering fraction, example 107
 - volcanic layer 11, 37
- albedo
 - Bond 118
 - δ -Eddington approximation 120
 - earth 4, 26, 27, 32, 33, 35, 197, 198
 - Eddington approximation 120
 - planar, planetary 106
 - single scattering 79
 - spherical 118
 - zonal 35
- angular momentum 155
 - quantum number, component fixed in space 158
 - quantum number, total 155, 158
 - units, Planck's constant 53, 155
- anharmonic oscillation 158
- astronomical unit (AU) 3, 219
- asymmetric top molecule 157
- atmospheric composition 14
- average radiance
 - angular 115
 - partly cloudy sky, infrared 126
 - wavelength, band average 150
 - wavelength, blackbody 56, 225
- average transmission
 - apparent breakdown of exponential law 150, 159, 165
 - correlated k 178, 180, 182
 - exponential sum-fit 177, 182
 - inhomogeneous path 166
 - nonoverlapping lines 169
 - overlapping lines 171
 - overlapping molecular bands 182
 - random model, Goody 176

- average transmission (*contd.*)
 - random model, Malkmus 179
 - single, pressure-broadened, strong line limit 164
 - weak line limit 163
- azimuthal component, radiance and phase function 112
- azimuthally averaged
 - phase function 113
 - radiance 112

b

- Babinet's principle. *See* diffraction
- ballistic bolometer 47
- Beer-Bouguer-Lambert law 68, 126, 159
- blackbody
 - radiating temperature, cloud 62
 - radiating temperature, zonal average 35
 - radiation, Planck function 52
 - radiative equilibrium temperature 5
 - spectral irradiances, examples 54, 61
 - Stefan-Boltzmann law 5
 - sun, as a blackbody 26, 53–55
 - Wien's displacement law 51, 55, 62
- Boltzmann distribution 51, 154, 164
- Bond albedo 118

c

- carbon dioxide, CO₂
 - absorption cross section, example 69, 81
 - absorption of sunlight 185
 - concentration 14
 - column amount, path to space 205
 - concentration 18
 - concentration increase, fossil fuels 10, 209
 - concentration variations, natural 10
 - doubling 209
 - effective pressure, path to space 205
 - electric dipole 19, 154
 - emitted radiance, 15 μ m 81, 209, 212
 - mass mixing ratio 18
 - pressure weighted amount 205
 - radiative forcing 11, 209, 210
 - random model parameters 175, 205, 227
 - stratospheric emission 26, 214
 - stratospheric temperature change 213
 - strong, pressure-broadened line limit 205
 - surface temperature change 12
 - vibration-rotation band, 15 μ m 29, 154, 156
 - weak line limit 207
- Chandrasekhar, S. 111, 135
- chlorofluorocarbons, CFCs 14, 170, 190, 217
- climate feedbacks 8, 31, 33, 38

- climate sensitivity 8
 - greenhouse forcing and greenhouse effect 8
 - uncertainty 31
 - window-gray model 12
- cloud
 - absorption, infrared 125
 - absorption, near infrared 194
 - effective fraction 126
 - emission by overcast regions 125
 - extinction cross section 69
 - greenhouse forcing 30
 - hydrometeor 66
 - longwave radiative forcing 29
 - optical depth, example 69
 - scattering phase function, example 75
 - shortwave radiative forcing 31
 - single scattering albedo, infrared 125
 - single scattering albedo, visible light 120
- Cloud and Earth's Radiant Energy System, CERES
 - blackbodies 50
 - Earth's radiation budget 32
 - radiometer 47
 - zonal average radiative fluxes 35
- cm-STP 18
- column amount 17
 - carbon dioxide 205
 - ozone 17
 - water vapor 192
- Community Climate System Model (CCSM) 33, 34
- conservation of energy
 - adiabatic process 23
 - first law of thermodynamics 2
- conservative scattering 119, 122
- cool to space approximation 101, 215
- cosine series 111, 112
- critical lapse rate 24
- cross section 65
 - absorption 77
 - scattering and differential scattering 70
 - extinction 66
- Curtis-Godson approximation 169, 182, 205, 206

d

- daylight hours 60, 61
- declination of the sun 59
- degeneracy 158
- δ -Eddington approximation 130
 - scaled optical properties 132
 - scattering phase function 130

- transmittance, total, diffuse, and direct beam 132
- δ - M method 137, 139
- dielectric media 41, 76
- diffraction 74, 125
- diffuse reflector 124
- diffusion length 119
- diffusivity factor 95
 - diffusely scattered light 188, 192
 - infrared radiation 95, 204
 - strong, pressure-broadened line limit 183
 - weak line limit 183
- dipole, electric
 - oscillating 42, 154, 155
 - permanent 153
- Dirac delta function 102, 130, 159, 162
- direct solar beam
 - attenuated by the atmosphere 102, 126
 - top of the atmosphere 58, 102, 127
- discrete ordinate method and DISORT 119, 132, 135
- division of atmosphere into layers 186, 195
- doppler broadening 162
- doubling layers 139

e

- Earth's energy budget 3, 26, 30
- Earth's orbit 61, 219
- Eddington approximation 114, 195, 224
 - adding layers 121
 - adding surface albedo 123
 - clouds, infrared 124
 - reflectance and transmittance, examples 120
- Einstein, A. 53, 154
- elastic scattering 65
- electric field vector 43, 72, 154
- electromagnetic waves 41, 52, 72, 111, 138
- electronic transition 152
- emission level and emitting layer 91, 93, 98
- emissivity 6, 90, 92, 125
- equation of state, ideal gas 3, 16, 161
- equivalent width 164
 - random band model 174, 176
 - strong, pressure-broadened line limit 165, 171
 - weak line limit 164, 170
- evaporation and evapotranspiration 24, 30
- exponential extinction. *See* Beer-Bouguer-Lambert law
- exponential integral function 95
- exponential sum-fit transmission model 177, 182

- extinction coefficient and cross section 69
- extinction of species 121

f

- first law of thermodynamics 2
- flat plate radiometer 63
- formal solution, radiative transfer equation. *See* radiative transfer equation
- Fourier decomposition 112

g

- gas constant 3, 16, 219
- global annual mean radiative imbalance 29, 32
- Goody random band model 176
- Goody, R.M. 173
- gray body 6, 30
- greenhouse effect 6
- greenhouse forcing 8, 30, 31
- greenhouse gas 1, 31, 93, 99, 212

h

- harmonic oscillator 152, 158
- haze. *See* aerosol
- heat capacity 219
 - air 3
 - Earth 9
 - surface 13
 - water 38
- heating rate
 - cloud-free solar due to water vapor 193, 195, 200
 - cool to space approximation 101, 215
 - first law of thermodynamics 3
 - infrared 25, 93, 98
 - overcast solar due to water vapor 197, 201
 - radiative 21, 25, 100, 116, 178
 - radiative–convective equilibrium 25
 - solar 25
- Henye-Greenstein phase function 82, 108, 132, 144
- hot bands 158
- hour angle 58
- hours of daylight 60, 61
- hydrometeor 66, 194
- hydrostatic balance 22, 23, 90

i

- ice crystals 26, 66, 69, 76, 124, 194
- ideal gas law 3, 16, 161
- impedance of free space 43
- incomplete gamma function 91
- index of refraction 72
- infrared radiation 1

infrared radiation (*contd.*)

- diffusivity factor 95, 204
- emission level and emitting layer 91, 93
- heating rate. *See* heating rate
- wavelength range, Earth 1, 41, 56

infrared spectra

- CO₂ 15 μ m band 156
- H₂O rotation band 157
- N₂O 8.6 μ m band 153
- surface 28
- top of atmosphere 28, 94, 212

infrared window, Earth's atmosphere 28, 30, 49, 54, 56, 62, 100, 143, 145, 217

inhomogeneous atmospheric path 124, 137, 139, 166, 174, 176, 178

integration factor 13, 87, 221

internal energy 2, 152

inverse laplace transform 178

irradiance 46, 53, 58, 90

isotropic phase function 74, 75, 135, 136

isotropic radiation 43, 46, 51–53, 212

k

k-distribution method 178, 182

Kirchoff's radiation law 6

Kronecker delta symbol 111

l

Lambertian reflector 124

Laplace transform 178

lapse rate 24

latent heat 26, 219

Legendre polynomials 75, 114, 130, 135

Liou, K-N. 136

local thermodynamic equilibrium 79, 86, 88, 154

longwave radiation. *See* infrared radiation

Lorentz half-width 162

Lorentz line shape factor 161

Lorentz, H.A. 159, 165

Lorenz–Mie theory. *See* Mie theory

m

magnetic field vector 42

Malkmus random band model 179

mass mixing ratio 16

Maxwell, J.C. 41

– distribution 162

– equations 43, 72, 75

methane, CH₄

– concentration 10, 14

– electric dipole moment 19

– greenhouse forcing with N₂O 31

– residence time 14

Mie theory 77

moment of inertia, rigid rotor 155

Monte Carlo simulation 140

Montreal protocol 190

Mt. Pinatubo eruption 11, 37

n

near infrared

– absorption of sunlight by clouds 194

– absorption of sunlight by water vapor 26, 27, 191

– wavelengths 27

net radiative flux 20, 21, 26, 30, 34, 35, 115

– longwave 98, 101, 210, 213, 214

– shortwave 196

nitrous oxide, N₂O

– absorption spectra, 8.6 μ m band 155, 158

– concentration and residence time 14

– electric dipole moment 18, 153

– greenhouse forcing with CH₄ 31

nonlocal thermodynamic equilibrium 154

nuclear winter 120

o

obliquity, Earth's orbit 59, 219

ocean mixed layer 9

optical depth 78

– examples 69

– path to space 91

– scaled, δ -Eddington approximation 132

orthonormal reslationships

– cosines 111

– Legendre polynomials 113

oscillating dipole 19, 154

– polarization of the radiation 43

– power radiated 47

– radiation pattern 42

ozone hole 191

ozone, O₃

– 9.6 μ m vibration-rotation band 29, 100, 216

– absorption cross sections, UV 189

– absorption cross sections 81, 231

– absorption of UV 27, 186, 190, 212

– absorption of UV-B 191, 198

– absorption of visible light 186, 191

– concentration 14, 18, 190

– electric dipole moment 18, 153

– residence time 14

p

P branch 153, 156

paleoclimate

- changes in atmospheric composition 10
- extinction of species 121
- parametric models 185
- perihelion, Earth's orbit 60, 219
- permeability and permittivity
 - dielectric media 72
 - free space 43
- phase function. *See* scattering phase function
- photochemical reactions 16, 18, 57, 115
- photon 50, 54, 119, 140, 153
- planar albedo. *See* albedo, planar
- Planck function. *See* blackbody, radiation, Planck function
- Planck's radiation constants 53, 219
- polarization 43, 51, 72, 76, 124
- precipitable water, *See also* column amount, water vapor
- pressure weighted amount 169
 - CO₂, path to space 205
 - water vapor, path to space 192
- pressure-broadened line
 - equivalent width, strong line limit 165
 - half-width 162
 - shape factor 161
- q**
- Q branch 156
- quantum mechanics
 - degeneracy 158
 - electric dipole transition rules 155
 - electronic transitions 19, 152
 - molecular energy levels 152
 - photon. *See* photon
 - rotational energy 156
 - rotational transitions 156
 - vibrational energy 152
 - vibrational transitions 153, 158
- r**
- R branch 153, 156
- radiance 46, 52, 58
 - diffuse 104, 126
 - direct beam 102, 104, 126
 - downward 86
 - surface downward, emitted 28
 - surface downward, transmitted 105
 - top of atmosphere, emitted 28, 94, 209, 212
 - upward 88
- radiating temperature. *See* blackbody and emission level
- radiative equilibrium
 - Earth 3, 26
 - radiative forcing 9
 - stratosphere 26, 214
 - temperature 4, 5, 34, 35
 - temperature profile, Earth 23
 - tropopause 25, 211
 - window-gray model 7, 19
- radiative flux, *See also* net radiative flux 20, 46
 - blackbody. *See* blackbody
 - incident solar, Earth 27, 30, 35, 58
 - longwave downward, surface 26, 30
 - longwave emitted, top of atmosphere 26, 30, 33, 35, 208, 210
 - shortwave downward, surface 27, 106, 118, 124, 132
 - shortwave reflected, top of atmosphere 26, 27, 30, 106, 117
- radiative flux density 46
- radiative forcing 9, 210
 - aerosol direct 199
 - aerosol indirect 200
 - chlorofluorocarbons, CFCs 217
 - cloud, longwave 29
 - cloud, shortwave 31
 - CO₂, doubling 11
 - volcanic, Mt. Pinatubo 11, 37
- radiative heating rate. *See* heating rate
- radiative time constant 13
- radiative transfer equation 77
 - adding-doubling method 138
 - δ -Eddington approximation 132
 - diffuse radiances 126
 - discrete ordinate method, DISORT 135
 - Eddington approximation 114, 116, 128
 - formal solution 86
 - formal solution, absorption and emission 88
 - formal solution, scattering and absorption 102
 - Monte Carlo simulation 140
 - single scattering approximation 103
 - spherical harmonic decomposition 111, 135
 - sunlight and infrared radiation, Earth 80
- radiative-convective equilibrium 24
- Ramanathan, V. 170
- Rayleigh scattering 18, 31, 80, 194
 - extinction cross section 69
 - optical depth 69, 187
 - phase function 74, 82
 - reflectance, δ -Eddington approximation 133
 - reflectance, Eddington approximation 120, 135
 - reflectivity 109

- Rayleigh scattering (*contd.*)
 - upward scattering fraction 106
 - Rayleigh–Jeans approximation 51
 - recursion relation, Legendre polynomials 113
 - reflectance 90, 117, 122
 - examples, Eddington and δ -Eddington approximations 133
 - examples, Eddington approximation 120
 - reflectivity 90, 105, 136, 138, 143
 - remote sensing
 - aerosol optical depth 143
 - surface temperature and atmospheric temperature profile 93
 - residence time
 - aerosols 18
 - trace gases 14
 - right ascension, sun 59
 - rigid rotor molecule 153
 - rotation band 29, 154, 157
 - rotation constant 155
 - rotational energy 153
 - degeneracy 158
 - rigid rotor 155
 - rotational partition function 158
 - rotational transition 154
 - rotational wavenumber 155
- s**
- saturated absorption, line center
 - CO₂ 15 μ m band 205
 - strong, pressure-broadened line limit 165
 - water vapor, near infrared 193
 - water vapor, rotation band 216
 - scale height
 - atmosphere 15
 - ozone 17
 - water vapor 15
 - scattering coefficient 78
 - scattering cross section 68
 - scattering phase function 71
 - asymmetry parameter 76
 - cumulative distribution 82, 141
 - δ -Eddington approximation 130
 - Eddington approximation 114
 - examples 75
 - Henyey-Greenstein 76
 - Mie theory 75
 - upward scattering fraction 106
 - Schuster and Schwarzschild, two-stream approximation 128
 - shortwave radiation. *See* solar radiation
 - similarity principle 132
 - single scattering albedo 79
 - size parameter 72
 - skin cancer 190
 - solar constant 3, 53, 219
 - solar radiation
 - absorption, atmosphere 26, 30, 197
 - absorption, ozone, UV 27, 186, 190, 198, 212
 - absorption, ozone, visible light 27, 186, 191
 - absorption, surface 26, 30, 197
 - absorption, water vapor, near infrared 197
 - effective radiating temperature 27, 53, 55, 189
 - incident, Earth 4, 26, 27, 30, 34, 35, 58
 - reflected, Earth 4, 26, 27, 30, 35, 197
 - wavelengths 1, 41, 55
 - Solar Radiation and Climate Experiment, SORCE 4, 32, 189
 - solar zenith angle 5, 58, 79
 - solid angle 44, 46, 50, 63, 66
 - source function 86
 - absorption and emission 86
 - scattering and absorption 86
 - spectrally averaged transmission. *See* average transmission
 - speed of light 41, 43, 72, 219
 - spherical albedo 118, 120
 - Stamnes, K. 137
 - Stephan–Boltzmann law 5, 53, 225
 - stimulated emission 154
 - strong, pressure-broadened line limit 164
 - subsolar point 58
 - surface
 - absorption, longwave 7, 26, 30
 - absorption, shortwave 26, 30
 - albedo 5, 36, 123, 193, 198
 - downward shortwave flux, Earth 27
 - energy budget, Earth 26, 30
 - energy budget, window-gray model 7, 13, 37
 - surface temperature
 - global average annual mean, Earth 6
 - radiative–convective model, cloud-free 23
 - role in climate feedbacks 8
 - sensitivity to radiative forcing and atmospheric composition 8
 - window-gray model 7
 - symmetric top molecule 157
- t**
- terrestrial radiation. *See* infrared radiation
 - thermal inertia 9
 - thermal infrared 54
 - thermal radiation. *See* Infrared radiation
 - top of atmosphere 3

transmissivity, *See also* average transmission
 68, 81, 89, 90, 105, 138, 139, 150
 transmittance 90, 95, 106, 118, 119, 122, 125
 – examples, Eddington and δ -Eddington
 approximations 133
 – examples, Eddington approximation 120
 tropopause 16, 25, 210
 two-stream approximation 128

u

U.S. Standard Atmosphere 25
 ultraviolet catastrophe 51
 ultraviolet radiation, UV 54
 – absorption by ozone 17, 27, 186, 190
 – absorption cross sections, ozone 189, 231
 – UV-B 191
 UV incident solar radiative flux 189

v

van de Hulst, J.C. 132
 vibrational state 152
 vibration-rotation band 156
 – CO₂ 15 μm band 29, 156
 – H₂O 6.3 μm band 29
 – N₂O 8.6 μm band 153
 – O₃ 9.6 μm band 29
 – random model parameters,
 CO₂ 175, 205, 227

visible light

– absorption by ozone 27, 191
 – absorption cross sections, ozone 231
 – extinction cross section, example 69
 – optical depth, example 26, 69
 – Rayleigh scattering, optical depth 187
 – top of atmosphere 55, 197, 198
 – wavelengths 1
 Voigt line shape 162
 volcanic haze. *See* aerosol, volcanic layer
 volume mixing ratio 18

w

wavenumber 28, 41
 weak line limit 163
 Wien's displacement law 51, 55, 62
 window-gray approximation
 – single-layer, radiative equilibrium
 model 6, 36
 – two-layer, radiative equilibrium
 model 19, 38

z

zonal mean radiation budget 35

