





Louis J. Battan

THE UNIVERSITY OF CHICAGO PRESS Chicago and London

Radar Observation of the Atmosphere



| | Pre | face | ix |
|---|-------------------------|--|-------------|
| 1 | Dringinlag of Dodor | | 1 |
| 1 | 1.1 | Radar Indicators | 4 |
| 2 | Some Properties of Ele | ctromagnetic Waves | 10 |
| | 2.1 | Electric Field | 10 |
| | 2.2 | Magnetic Field | 11 |
| | 2.3 | Radiation of Energy by a Radar | |
| | | Antenna | 12 |
| | 2.4 | Polarization of Electromagnetic Waves | 15 |
| 3 | Propagation of Electron | nagnetic Waves | 17 |
| | 3.1 | Meteorological Factors Determining | |
| | | the Index of Refraction | 18 |
| | 3.2 | Simple Refraction | 21 |
| | 3.3 | Refraction in the Lower Troposphere | 22 |
| | 3.4 | Curvature of Ray Paths Relative | |
| | | to the Earth | 23 |
| | 3.5 | Nonstandard Refraction | 24 |
| | 3.6 | Meteorological Conditions Associated | |
| | | with Nonstandard Refraction | 26 |
| 4 | Radar Detection of Sph | erical Particles | 29 |
| | 4.1 | An Approximate Form of the Radar | |
| | | Equation | 29 |
| | 4.2 | A More Exact Form of the Radar | |
| | | Equation | 32 |
| | 4.3 | Fluctuating Echoes from Distributed | |
| | | Scatterers | 33 |
| | 4.4 | Measuring $\overline{P_r}$ by Threshold Techniques | 34 |
| | 4.5 | Backscattering by Small Spherical | |
| | , | Water or Ice Spheres | 36 |
| | | and an | 1000 C 1000 |

V

| 4.6 | Complex Index of Refraction | 38 |
|---------------------------|---|-----|
| 4.7 | Range of Rayleigh Backscattering | 40 |
| 4.8 | $\overline{P_r}$ and the Backscattering from a Region | |
| | of Spherical Particles | 42 |
| 4.9 | Effective Radar Reflectivity Factor | 43 |
| | | |
| 5 Backscattering by Melt | ing Spheres and | 15 |
| Nonspherical Particles | | 45 |
| 5.1 | Backscattering by Small, Melting | 15 |
| 5.0 | Ice Spheres | 45 |
| 5.2 | Backscattering by Large, Melting | 40 |
| | Ice Spheres | 48 |
| 5.3 | Backscattering from Spheres of | 10 |
| 5.4 | "Spongy" Ice | 49 |
| 5.4 | Scattering by Small, Nonspherical | 50 |
| | Hydrometeors | 53 |
| 5.5 | Depolarization by Nonspherical | 50 |
| | Particles | 38 |
| 5.6 | Backscattering by Large Spheroids | 62 |
| | | |
| 6 Attenuation | | 64 |
| 6.1 | Attenuation by Atmospheric Gases | 65 |
| 6.2 | Attenuation by Hydrometeors | 67 |
| 6.3 | Attenuation by Clouds | 69 |
| 6.4 | Attenuation by Rain | 70 |
| 6.5 | Attenuation by Snow | 73 |
| 6.6 | Attenuation by Hail | 75 |
| 2 | | |
| 7 Use of Radar for Precir | nitation Measurements | 84 |
| 7.1 | Calculation of Radar Constant | 84 |
| 7.2 | Particle-Size Distributions in the | |
| | Atmosphere | 85 |
| 7.3 | Relationship of Z to Liquid-Water | |
| | Content and Precipitation Rate | 88 |
| 7.4 | Comparison of Calculated and Observed | |
| | Values of Precipitation Intensity | 97 |
| 7.5 | Rain-Intensity Measurements at | |
| | Attenuating Wavelengths | 101 |
| 7.6 | Estimation of R from Attenuation | |
| | Measurements | 103 |
| 7.7 | Measurement of Rainfall Over an Area | 104 |

vi

| 8 Pulsed Doppler R | adar | 114 |
|------------------------|--|-----|
| | 8.1 The Doppler Shift Frequency | 114 |
| | 8.2 A Pulsed-Doppler Radar | 115 |
| | 8.3 Doppler Frequency and Fluctuation | |
| | Frequency | 117 |
| | 8.4 The Doppler Spectrum | 119 |
| | 8.5 The Spread of the Doppler Spectrum | 123 |
| | 8.6 Signal Fluctuations | 126 |
| | 8.7 Measurement of Turbulence | 128 |
| | 8.8 Measurement of Updraft Velocities | 129 |
| | 8.9 Measurement of the Size Distribution | |
| | of Scatterers | 139 |
| | 8.10 Measurement of Wind Speed | 145 |
| | 8.11 Simultaneous Observations with | |
| | More than One Doppler Radar | 154 |
| | 8.12 Plan Shear Indicator (PSI) | 157 |
| | 8.13 Specialized Doppler Radars | 159 |
| 9 Distortion of Ech | oes Resulting from Finite | |
| Pulse Length and | Beam Widths | 162 |
| a more compression and | 9.1 Pulse-Length Effects | 162 |
| | 9.2 Beam-Width Effects of the Major Lobe | 164 |
| | 9.3 Effects of Side Lobes | 166 |
| | 9.4 Other Factors Distorting Echoes | 171 |
| 10 Use of Radar in | Cloud Physics Research | 173 |
| To ese of Radar III | 10.1 Precipitation in Convective Clouds | 173 |
| | 10.2 Vertical Extent of Convective Clouds | 179 |
| | 10.3 Growth of Convective Clouds | 180 |
| | 10.4 Duration of Convective Echoes | 183 |
| | 10.5 Hail in Convective Clouds | 185 |
| | 10.6 Continuous Precipitation | 188 |
| | 10.7 Bright Band | 190 |
| | 10.8 Precipitation-Generating Levels | 170 |
| | and Snow Trails | 195 |
| | 10.9 Cloud-Seeding Tests | 197 |
| 11 Radar Observati | ions of Medium- and Large- | |
| Scale Systems | the second secon | 201 |
| | 11.1 Thunderstorms | 201 |
| | 11.2 Thunderstorm Movement | 209 |

| 11.3 | Lines of Thunderstorms-Squall | |
|-------|---|---|
| | Lines | 211 |
| 11.4 | Use of Chaff Winds to Study | |
| | Thunderstorms | 217 |
| 11.5 | Observations of Lightning | 220 |
| 11.6 | Tornadoes | 226 |
| 11.7 | Hurricanes | 230 |
| 11.8 | Observations of Cyclonic and | |
| | Frontal Precipitation | 238 |
| | | |
| | | 245 |
| 12.1 | Types of Angel Echoes | 245 |
| 12.2 | Dot Angels | 246 |
| 12.3 | Angels in Layers | 253 |
| 12.4 | Lines of Echoes on | |
| | Conventional Radars | 258 |
| 12.5 | Study of Convection in Clear Air | 263 |
| 12.6 | Clear-Air Turbulence (CAT) | 267 |
| 12.7 | Wave Motions and Turbulence | 268 |
| | | |
| Appe | ndix | 275 |
| Refer | ences | 281 |
| Index | | 319 |
| | 11.3 11.4 11.5 11.6 11.7 11.8 12.1 12.2 12.3 12.4 12.5 12.6 12.7 Appee Refer Index | 11.3 Lines of Thunderstorms – Squall Lines 11.4 Use of Chaff Winds to Study Thunderstorms 11.5 Observations of Lightning 11.6 Tornadoes 11.7 Hurricanes 11.8 Observations of Cyclonic and Frontal Precipitation 12.1 Types of Angel Echoes 12.2 Dot Angels 12.3 Angels in Layers 12.4 Lines of Echoes on Conventional Radars 12.5 Study of Convection in Clear Air 12.6 Clear-Air Turbulence (CAT) 12.7 Wave Motions and Turbulence |

viii