Developments in Atmospheric Science 14

E.E. GOSSARD and R.G. STRAUCH

Radar Observation of Clear Air and Clouds

Developments in Atmospheric Science, 14

Radar Observation of Clear Air and Clouds

E.E. GOSSARD and R.G. STRAUCH

NOAA/ERL/Wave Propagation Lab., Boulder, CO 80303, U.S.A.



ELSEVIER Amsterdam - Oxford - New York 1983

	CONTENTS	Page
PREFACE		V
ACKNOWLED	OGMENTS	VII
CHAPTER 1	- INTRODUCTION	1
221.1	RADAR RETURNS FROM HYDROMETEORS	1
	1.1.1 Review	1
	1.1.2 Relationships between cloud types and weather systems	3
	(i) Cloud classification	3
	(ii) Clouds and storm system morphology	6
1.2	CLEAR-AIR RADAR RETURNS	19
	1.2.1 Review	19
	1.2.2 Refractive index of the clear atmosphere	21
	1.3.1 Air masses	26
	(i) Source and formation	26
	(ii) Air mass modification the surface layers	31
	1.4.1 Elevated layers	33
	(i) Layers capping the convective boundary layer	33
	(ii) Sub-tropical subsidence layers	36
	(iii) Frontal discontinuities	41
	(iv) The stratosphere and the middle atmosphere	49
CHAPTER 2	- PHYSICAL EFFECTS OF THE ATMOSPHERE ON RADAR WAVES	53
2.1	INTRODUCTION	53
2.2	REFLECTION AND REFRACTION	53
2.3	ABSORPTION	54
2.4	SCATTERING - GENERAL	54
	2.4.1 Scatter from clouds and precipitation	60
	2.4.2 Scatter from the clear air	62
	2.4.3 Scattering and the refractive index structure parameter	64
	2.4.4 Refractive index variance of clear air	65
	2.4.5 Effect of temperature-humidity covariance	66
2.5	BRAGG SCATTER FROM THE AIR COMPARED WITH BRAGG SCATTER FROM A	
	DROPLET MEDIUM	67
	2.5.1 Temperature-humidity covariance in clouds	68
2.6	FORWARD-SCATTER OBSERVATION OF BRAGG-COHERENCE IN CLOUDS	69
2.7	CONCLUSIONS	80
CHAPTER 3	- A LITTLE CLOUD PHYSICS	83
3.1	SOME DEFINITIONS AND NOMENCLATURE	83

IX

Х

CHAPTER 4 - RADAR REFLECTIVITY AND CLOUD CHARACTERISTICS

89

4.1	INTRODUCTION	89
4.2	DROP-SIZE DISTRIBUTION - SOME SPECIAL CASES	89
4.3	A GENERAL DROP-SIZE DISTRIBUTION FUNCTION	91
4.4	METHODS FOR MEASURING DROP-SIZE IN-SITU	95
4.5	OBSERVATIONS OF DROP-SIZE DISTRIBUTION IN NATURAL CLOUDS	97
4.6	OBSERVATIONS OF DROP-SIZE DISTRIBUTION IN MAN-MADE CLOUDS	102
4.7	OBSERVATIONS OF CLOUD REFLECTIVITY	102
4.8	CONCLUSIONS	105
CHAPTER 5	- RADAR ATTENUATION AND CLOUD OBSERVATION	107
5.1	INTRODUCTION	107
5.2	ATTENUATION OF RADAR WAVES BY SMALL WATER DROPS	107
5.3	OPTICAL EXTINCTION BY SMALL WATER SPHERES	109
5.4	CLOUD AND RAIN PARAMETER DIAGRAMS	110
5.5	MEASURING Z AND k	111
5.6	ANALYSIS OF ERRORS	113
5.7	CONCLUSIONS	114
CHAPTER 6	- POLARIZATION AND SCATTERER CHARACTERIZATION	117
6.1	INTRODUCTION	117
6.2	BACKSCATTER BY NON-SPHERICAL PARTICLES	119
	6.2.1 Discussion	119
	6.2.2 Theory	119
	6.2.3 Geometry of scattering	122
	6.2.4 Perfect sphere	125
	6.2.5 Random orientation	125
	6.2.6 Oriented oblate spheroids	125
	6.2.7 Oriented prolate spheroids	126
6.3	DIFFERENTIAL REFLECTIVITY FROM NON-SPHERICAL PARTICLES	127
6.4	ATTENUATION BY NON-SPHERICAL PARTICLES	131
6.5	SCATTERING IN AN ARBITRARY DIRECTION	132
6.6	CONCLUSIONS AND POSSIBLE OBSERVATIONAL APPLICATIONS	133
CHAPTER 7	- DOPPLER RADAR OBSERVATIONS OF CLOUDS AND STORMS	139
7.1	DOPPLER RADAR MEASUREMENTS	139
7.2	ATMOSPHERIC TURBULENCE AND DOPPLER VELOCITY SPECTRAL WIDTH	142

		XI
7.3	MULTI-RADAR DOPPLER SYSTEMS	148
	7.3.1 Introduction	148
	7.3.2 Three-dimensional wind fields in storms observed by Dopple	er
	radar	150
	7.3.3 Particle fall velocity	153
	7.3.4 Boundary conditions	153
7.4	DOPPLER RADAR STUDIES OF THE CLEAR AIR	155
	7.4.1 The use of chaff in studies of the clear air	155
	7.4.2 Dual Doppler radar measurements in the clear air without	
	chaff	159
7.5	FREQUENCY-MODULATED, CONTINUOUS-WAVE (FM-CW) RADAR	161
7.6	DOPPLER RADAR WINDS IN THE STRATOSPHERE AND MIDDLE ATMOSPHERE	168
CHAPTER 8	- BIOLOGICAL TARGETS AND THEIR ROLE IN RADAR BACKSCATTER	171
CHAPTER 9	- BOUNDARY LAYER STRUCTURE AND RADAR REFRACTION, DUCTING AND	
	SCATTERING	179
9.1	INTRODUCTION	179
9.2	REFRACTIVE INDEX STRUCTURE OF THE BOUNDARY LAYER	182
9.3	STRUCTURE PARAMETER OF REFRACTIVE INDEX IN THE BOUNDARY LAYER	188
CHAPTER 1	0 - BOUNDARY LAYERS UNDERGOING MODIFICATION	193
10.1	INTRODUCTION	193
10.2	SPATIAL TRANSITION AT THE LOWER BOUNDARY	194
	10.2.1 Traditional diffusion equation approach	194
	10.2.2 Flux intregral method	197
	10.2.3 Logarithmic profiles	199
10.3	BOUNDARY LAYER MODIFICATION DUE TO RADIATIONAL COOLING OF THE	
	GROUND	203
	10.3.1 Constant flux assumption at lower boundary	203
	10.3.2 Quasi-sinusoidal variation of surface temperature	207
CHAPTER 1	1 - CONSIDERATIONS FOR RADAR DATA PROCESSING SYSTEMS	211
11.1	INTRODUCTION	211
11.2	SIGNAL CORRELATION	211
11.3	RADAR SENSITIVITY	212
11.4	ESTIMATION OF SPECTRAL MOMENTS - "PULSE-PAIR" PROCESSING	217
11.5	FM-CW DOPPLER RADAR	221
11.6	PROCESSING AND AVERAGING RADAR MEASUREMENTS FOR WIND SOUNDING	225

XII

CHAPTER 12 - VARIOUS RADARS AND THEIR POTENTIAL FOR CLOUD AND CLEAR-AIR SOUNDING

12.1 INTRODUCTION	229
12.2 TYPES OF METEOROLOGICAL RADARS	229
12.3 WAVELENGTH CONSIDERATIONS FOR CLOUD AND CLEAR-AIR RADARS	232
12.3.1 Radars for cloud studies	233
12.3.2 Radars for clear-air probing	234
12.3.3 Effect of attenuation on choice of wavelength	237
12.4 VARIOUS RADARS IN CURRENT USE AS CLOUD AND CLEAR-AIR SOUNDERS	240
APPENDIX A - SOME FUNDAMENTAL RADAR RELATIONSHIPS	243
A.1 THE RADAR EQUATION	243
A.2 RADAR REFLECTIVITY AND BACKSCATTER	244
A.3 BACKSCATTER FROM SPHERICAL DROPS	246
A.4 DOPPLER RADARS	247
A.4.1 Pulse radars	247
A.4.2 FM-CW radars	248
APPENDIX B - RELATIONSHIPS BETWEEN N AND ϕ	251
APPENDIX C - TABLES OF THE INCOMPLETE GAMMA FUNCTION	254
APPENDIX D - RELATIONSHIP BETWEEN DOPPLER SPECTRAL WIDTH AND TURBULENCE	255
APPENDIX E - VARIOUS SPECTRAL FORMS AND CONSTANTS; THE ENERGY BALANCE	
EQUATIONS	259
E.1 SOME SPECTRAL RELATIONSHIPS	259
E.2 THE BALANCE EQUATIONS FOR KINETIC ENERGY AND TEMPERATURE	261
E.3 THE SPECTRAL FORMS AND CONSTANTS	261
E.4 THE REFRACTIVE INDEX FIELD	263
REFERENCES	265

SUBJECT INDEX

277

229