

Physical Principles of Remote Sensing

THIRD EDITION

W. G. REES

Scott Polar Research Institute
University of Cambridge



CAMBRIDGE
UNIVERSITY PRESS

CONTENTS

Preface	<i>page</i>	xv
Acknowledgements		xviii
1 Introduction		1
1.1 A short history of remote sensing		1
1.2 Applications of remote sensing		5
1.3 A systems view of remote sensing		6
1.4 Further reading, and how to obtain data		9
2 Electromagnetic waves in free space		11
2.1 Electromagnetic waves		11
2.2 Polarisation		15
2.3 Spectra and the Fourier transform		19
2.4 The Doppler effect		24
2.5 Describing angular distributions of radiation		25
2.6 Thermal radiation		28
2.6.1 Characteristics of solar radiation		34
2.7 Diffraction		36
Review questions		40
Problems		40
3 Interaction of electromagnetic radiation with matter		42
3.1 Propagation through homogeneous materials		43
3.1.1 Complex dielectric constants: absorption		44
3.1.2 Dielectric constants and refractive indices of real materials		45
3.1.3 Dispersion		49
3.2 Plane boundaries		52
3.3 Scattering from rough surfaces		56
3.3.1 Description of surface scattering		57
3.3.2 Simple models of surface scattering		59
3.3.3 The Rayleigh roughness criterion		62
3.3.4 Models for microwave backscatter		64
3.4 Absorption and scattering by particles		73
3.4.1 Very small particles		74
3.4.2 Larger particles		76
3.4.3 Absorption and scattering by atoms and molecules		78
3.5 The radiative transfer equation		84
3.5.1 Propagation through an absorbing medium		85
3.5.2 Propagation through an absorbing and emitting medium		86

3.5.3 A simple model of scattering and absorption: the two-stream approximation	89
3.5.4 Scattering, absorption and emission	93
3.6 Interaction of electromagnetic radiation with real materials	94
3.6.1 Visible and near-infrared region	95
3.6.2 Emissivities in the thermal infrared region	99
3.6.3 Emissivities in the microwave region	100
3.6.4 Effect of clouds and snow on microwave radiation	102
3.6.5 Microwave backscattering coefficients	103
3.6.6 Modelling microwave backscattering: case study of a snowpack	105
Review questions	107
Problems	108
4 Interaction of electromagnetic radiation with the Earth's atmosphere	110
4.1 Composition and structure of the gaseous atmosphere	110
4.2 Molecular absorption and scattering in the atmosphere	114
4.3 Particles in the atmosphere: aerosols	119
4.4 Fog and cloud	121
4.5 Rain and snow	125
4.6 The ionosphere	128
4.7 Atmospheric turbulence	131
Review questions	133
Problems	133
5 Photographic systems	135
5.1 Photographic film	135
5.1.1 Performance of photographic film: speed, contrast and spatial resolution	136
5.1.2 Digital photography	139
5.2 Photographic optics	141
5.2.1 Lens distortion	144
5.3 Photogrammetry and stereogrammetry	147
5.3.1 Relief displacement	149
5.3.2 Stereophotography	152
5.4 Atmospheric propagation	156
5.5 Some instruments	158
5.6 Applications of aerial and space photography	162
Review questions	162
Problems	163
6 Electro-optical systems	164
6.1 Visible and near-infrared imaging systems	164
6.1.1 Detectors	164
6.1.2 Imaging	167
6.1.3 Spatial resolution	170

Contents

6.1.4 Spectral resolution	171
6.1.5 Atmospheric propagation and correction	172
6.2 Types of VNIR imager	175
6.2.1 Very high resolution imagers	175
6.2.2 High resolution imagers	176
6.2.3 Medium resolution imagers	179
6.2.4 Low resolution imagers	179
6.2.5 Ocean colour imagers	180
6.2.6 Hyperspectral imagers	181
6.2.7 Geostationary imagers	182
6.3 Major applications of VNIR images	184
6.4 Thermal infrared imagers	188
6.4.1 Detectors	188
6.4.2 Thermal infrared imaging	189
6.4.3 Spatial resolution	189
6.4.4 Spectral resolution and sensitivity	190
6.4.5 Atmospheric propagation and correction	191
6.5 Types of TIR imager	194
6.5.1 High resolution TIR imagers	194
6.5.2 Medium resolution TIR imagers	194
6.5.3 Geostationary TIR imagers	196
6.6 Major applications of thermal infrared images	197
6.6.1 Earth surface temperature	198
6.6.2 Thermal inertia	199
6.6.3 Cloud detection and monitoring	204
6.7 Atmospheric sounding	206
6.7.1 Temperature profiling from observations at nadir	207
6.7.2 Profiling of gas concentrations at nadir	210
6.7.3 Backscatter observations at nadir	211
6.7.4 Limb-sounding observations	211
6.7.5 Spectral resolution for atmospheric sounding observations	213
6.8 Some profiling instruments	216
Review questions	220
Problems	221
7 Passive microwave systems	223
7.1 Antenna theory	223
7.1.1 Angular response and spatial resolution	223
7.1.2 Sensitivity	229
7.1.3 Scanning radiometers	229
7.2 Applications of passive microwave radiometry	232
7.2.1 Oceanographic applications	232
7.2.2 Land surface applications	235
7.3 Atmospheric correction of passive microwave imagery	239
7.4 Examples: the SSMIS and the MSMR	241

7.5 Atmospheric sounding using passive microwave observations	243
Review questions	247
Problems	248
8 Ranging systems	250
8.1 Laser profiling	250
8.1.1 Scanning laser profilers	253
8.1.2 Waveform-resolving laser profiling	255
8.1.3 Atmospheric correction of laser profiler data	255
8.1.4 Applications of laser profiling	257
8.2 Radar altimetry	261
8.2.1 Simple model of the waveform	261
8.2.2 Effect of the Earth's curvature	265
8.2.3 Effect of coherence: range accuracy	266
8.2.4 Response from a rough surface	267
8.2.5 Applications of radar altimetry	269
8.2.6 Atmospheric and ionospheric correction of radar altimeter data	273
8.2.7 Example: the Envisat RA-2 radar altimeter	275
8.3 Other ranging systems	277
Review questions	278
Problems	278
9 Scattering systems	281
9.1 LiDAR	281
9.2 The radar equation	282
9.3 Microwave scatterometry	285
9.3.1 Applications of microwave scatterometry	287
9.3.2 Example: ASCAT	291
9.4 Real-aperture imaging radar	292
9.4.1 Image distortions	294
9.4.2 Instruments and applications	296
9.5 Synthetic aperture radar	297
9.5.1 More exact treatment of the azimuth resolution	300
9.5.2 Speckle	301
9.5.3 Distortions of SAR images	304
9.5.4 Limitations imposed by ambiguity	306
9.5.5 SAR interferometry	307
9.5.6 Major applications of radar imaging	312
9.5.7 Example: Radarsat-2	314
Review questions	316
Problems	317
10 Platforms for remote sensing	318
10.1 Aircraft	318
10.2 Satellites	320

10.2.1 Launch of satellites	321
10.3. Description of the satellite orbit	325
10.3.1 Effects of the Earth's asphericity	329
10.3.2 Special orbits	331
10.4 Satellite station-keeping and orbital manoeuvres	343
Review questions	346
Problems	346
11 Data processing	348
11.1 Transmission and storage of data	348
11.2 Image processing	351
11.2.1 Preprocessing	352
11.2.2 Image enhancement	360
11.2.3 Band transformations	371
11.3 Image classification	380
11.3.1 Density slicing and pseudocolour display	381
11.3.2 Multispectral classification	381
11.3.3 Hyperspectral classification	385
11.3.4 Advanced classification methods	386
11.3.5 Sub-pixel classification	388
11.3.6 Texture classification	389
11.3.7 Error matrices and classification accuracy	390
11.4 Image segmentation and detection of geometrical features	394
11.4.1 Segmentation	394
11.4.2 Detecting shapes	395
11.5 Geographic information systems	402
11.6 Image formats and data compression	404
11.6.1 Image compression	404
11.6.2 Image formats for remote sensing	406
Review questions	409
Problems	410
Appendix: Data tables	412
A.1 Physical constants	412
A.2 Units	412
A.3 Illuminance at the Earth's surface	413
A.4 Properties of the Sun and Earth	414
A.5 Position of the Sun	414
References	417
Index	426

See colour plates section between pages 206 and 207.