

# Contents

Preface.....	xv
Author .....	xvii
<b>Chapter 1</b> Introduction .....	1
1.1 Definition and Objectives.....	1
1.2 Historical Background.....	4
1.3 International Space Law .....	9
1.4 Benefits of Environmental Monitoring from Satellite Sensors.....	13
1.4.1 Global Coverage .....	14
1.4.2 Synoptic View .....	15
1.4.3 Multiscale Observations.....	16
1.4.4 Observations over the Nonvisible Regions of the Spectrum .....	17
1.4.5 Repeat Observation .....	17
1.4.6 Immediate Transmission.....	18
1.4.7 Digital Format .....	18
1.5 Sources of Information on Remote Sensing Data .....	19
1.6 Review Questions .....	21
<b>Chapter 2</b> Physical Principles of Remote Sensing .....	23
2.1 Fundamentals of Remote Sensing Signals .....	23
2.2 Electromagnetic Spectrum .....	26
2.3 Terms and Units of Measurement.....	27
2.4 Electromagnetic Radiation Laws.....	30
2.5 Spectral Signatures in the Solar Spectrum.....	32
2.5.1 Introduction .....	32
2.5.2 Vegetation Reflectance.....	38
2.5.3 Soil Reflectance Properties .....	42
2.5.4 Water in the Solar Spectrum .....	46
2.6 Thermal Infrared Domain.....	49
2.6.1 Characteristics of EM Radiation in the Thermal Infrared.....	49
2.6.2 Thermal Properties of Vegetation.....	51
2.6.3 Soils in the Thermal Domain.....	52
2.6.4 Thermal Signature of Water and Snow .....	52
2.7 Microwave Region.....	53
2.7.1 Characteristics of Electromagnetic Radiation in the Microwave Region.....	53

	2.7.2	Characteristics of Vegetation in the Microwave Region.....	58
	2.7.3	Characteristics of Soil in the Microwave Region.....	59
	2.7.4	Water and Ice in the Microwave Region .....	60
2.8		Atmospheric Interactions .....	61
	2.8.1	Atmospheric Absorption .....	63
	2.8.2	Atmospheric Scattering.....	65
	2.8.3	Atmospheric Emission .....	66
2.9		Review Questions .....	66
<b>Chapter 3</b>		<b>Sensors and Remote Sensing Satellites .....</b>	<b>69</b>
	3.1	Resolution of a Sensor System .....	69
		3.1.1 Spatial Resolution.....	70
		3.1.2 Spectral Resolution.....	73
		3.1.3 Radiometric Resolution .....	73
		3.1.4 Temporal Resolution .....	74
		3.1.5 Angular Resolution .....	75
		3.1.6 Relationship between Different Resolution Types .....	76
	3.2	Passive Sensors .....	77
		3.2.1 Photographic Cameras .....	77
		3.2.2 Cross-Track Scanners .....	81
		3.2.3 Along-Track (Push-Broom) Scanners .....	82
		3.2.4 Video Cameras .....	83
		3.2.5 Microwave Radiometers.....	83
	3.3	Active Sensors .....	85
		3.3.1 Radar .....	85
		3.3.2 Lidar .....	93
	3.4	Satellite Remote Sensing Missions.....	99
		3.4.1 Satellite Orbits.....	99
		3.4.2 The Landsat Program.....	101
		3.4.3 SPOT Satellites .....	104
		3.4.4 Other Medium-Resolution Optical Sensors .....	106
		3.4.5 High-Spatial-Resolution Satellites .....	108
		3.4.6 Geostationary Meteorological Satellites .....	111
		3.4.7 Polar-Orbiting Meteorological Satellites.....	113
		3.4.8 Terra–Aqua.....	117
		3.4.9 Radar Missions.....	120
		3.4.10 Programs with Hyperspectral Sensors .....	123
	3.5	Review Questions .....	124
<b>Chapter 4</b>		<b>Basis for Analyzing EO Satellite Images .....</b>	<b>127</b>
	4.1	Constraints in Using Remote Sensing Data .....	127
		4.1.1 What Can Be Estimated from the EO Images .....	127
		4.1.2 Costs of Data Acquisition.....	129
		4.1.3 End-User Requirements .....	130

- 4.2 Types of Interpretation ..... 131
  - 4.2.1 Thematic Classification ..... 132
  - 4.2.2 Generation of Biophysical Variables ..... 132
  - 4.2.3 Change Detection ..... 132
  - 4.2.4 Spatial Patterns ..... 133
- 4.3 Organization of Remote Sensing Project ..... 133
  - 4.3.1 Description of Objectives ..... 133
  - 4.3.2 Scale and Resolution ..... 134
  - 4.3.3 Classification Typology ..... 137
  - 4.3.4 Selection of Imagery ..... 140
  - 4.3.5 Image Formats and Media ..... 141
  - 4.3.6 Selection of Interpretation Method: Visual or Digital Processing? ..... 141
- 4.4 Interpretation Phase ..... 143
- 4.5 Presentation of Study Areas ..... 145
- 4.6 Review Questions ..... 147

**Chapter 5** Visual Interpretation ..... 149

- 5.1 Characteristics of Photographic Images ..... 149
- 5.2 Feature Identification ..... 149
- 5.3 Criteria for Visual Interpretation ..... 151
  - 5.3.1 Brightness ..... 152
  - 5.3.2 Color ..... 153
  - 5.3.3 Texture ..... 157
  - 5.3.4 Spatial Context ..... 160
  - 5.3.5 Shape and Size ..... 160
  - 5.3.6 Shadows ..... 161
  - 5.3.7 Spatial Pattern ..... 163
  - 5.3.8 Stereoscopic View ..... 163
  - 5.3.9 Period of Acquisition ..... 164
- 5.4 Elements of Visual Analysis ..... 165
  - 5.4.1 Geometric Characteristics of a Satellite Image ..... 165
  - 5.4.2 Effect of Spatial Resolution in Visual Analysis ..... 166
  - 5.4.3 Effect of Spectral Resolution in Visual Analysis ..... 167
  - 5.4.4 Color Composites ..... 169
  - 5.4.5 Multitemporal Approaches ..... 170
- 5.5 Review Questions ..... 171

**Chapter 6** Digital Image Processing (I): Enhancements and Corrections ..... 173

- 6.1 Structure of a Digital Image ..... 173
- 6.2 Media and Data Organization ..... 176
  - 6.2.1 Data Storage ..... 176
  - 6.2.2 Image File Formats ..... 176
- 6.3 Digital Image Processing Systems ..... 177

6.4	General File Operations .....	179
6.4.1	File Management.....	179
6.4.2	Display Utilities.....	182
6.4.3	Image Statistics and Histograms.....	184
6.5	Visual Enhancements .....	189
6.5.1	Contrast Enhancement .....	189
6.5.1.1	Color Lookup Table .....	190
6.5.1.2	Contrast Compression.....	192
6.5.1.3	Contrast Stretch .....	193
6.5.2	Color Composites .....	198
6.5.3	Pseudocolor .....	200
6.5.4	Filters.....	201
6.5.4.1	Digital Filters.....	201
6.5.4.2	Low-Pass Filter .....	205
6.5.4.3	High-Pass Filter .....	206
6.6	Geometric Corrections .....	208
6.6.1	Sources of Errors in Satellite Acquisitions .....	208
6.6.2	Georeferencing from Orbital Models.....	211
6.6.2.1	Image Inclination.....	211
6.6.2.2	Panoramic Distortion.....	213
6.6.2.3	Effect of Earth's Curvature.....	214
6.6.3	Georeferencing from Control Points .....	215
6.6.3.1	Establishing Control Points .....	216
6.6.3.2	Calculating the Correction Function .....	217
6.6.3.3	Generation of the Georeferenced Image.....	221
6.6.4	Georeferencing with Digital Elevation Models.....	226
6.7	Radiometric Corrections .....	226
6.7.1	Solving Missed or Deteriorated Data.....	226
6.7.1.1	Restoration of Missing Lines and Pixels.....	226
6.7.1.2	Correction of Striping Effects .....	228
6.7.2	Conversion from DL to Radiance .....	230
6.7.3	Calculation of Reflectance .....	232
6.7.3.1	Simplified Reflectance.....	232
6.7.3.2	Atmospheric Correction .....	234
6.7.3.3	Topographic Shadow Corrections.....	241
6.7.3.4	Correction of Bidirectional Effects .....	245
6.7.4	Calculation of Temperature.....	249
6.8	Image Fusion Methods .....	253
6.9	Review Questions .....	257
<b>Chapter 7</b>	<b>Digital Image Processing (II): Generation of Derived Variables.....</b>	<b>259</b>
7.1	Generation of Continuous Variables.....	259
7.1.1	Inductive and Deductive Models in Remote Sensing .....	260
7.1.2	Principal Component Analysis.....	263

- 7.1.3 Spectral Vegetation Indices..... 269
  - 7.1.3.1 Ratio-Based VIs..... 271
  - 7.1.3.2 Optimized VIs ..... 275
  - 7.1.3.3 Orthogonal-Based VIs ..... 280
  - 7.1.3.4 Fluorescence Indices..... 285
- 7.1.4 Other Spectral Indices..... 285
- 7.1.5 Extraction of Subpixel Information..... 286
- 7.1.6 Lidar Data Processing ..... 293
- 7.2 Digital Image Classification ..... 297
  - 7.2.1 Introduction ..... 297
  - 7.2.2 Training Phase..... 299
    - 7.2.2.1 Basic Concepts..... 299
    - 7.2.2.2 Supervised Classification..... 301
    - 7.2.2.3 Unsupervised Classification..... 304
    - 7.2.2.4 Mixed Methods..... 308
    - 7.2.2.5 Analysis of the Training Statistics..... 309
  - 7.2.3 Assignment Phase ..... 314
    - 7.2.3.1 Minimum-Distance Classifier ..... 314
    - 7.2.3.2 Parallelepiped Classifier ..... 315
    - 7.2.3.3 Maximum Likelihood Classifier..... 316
    - 7.2.3.4 Decision Tree Classifier..... 322
    - 7.2.3.5 Neural Networks..... 324
    - 7.2.3.6 Fuzzy Classification..... 328
    - 7.2.3.7 Hyperspectral Classification..... 330
    - 7.2.3.8 Object-Oriented Classifiers..... 334
    - 7.2.3.9 Contextual Classifiers ..... 336
    - 7.2.3.10 Postclassification Generalization ..... 336
  - 7.2.4 Classification Outputs ..... 338
- 7.3 Techniques of Multitemporal Analysis ..... 341
  - 7.3.1 Temporal Domain in Remote Sensing Studies..... 341
  - 7.3.2 Prerequisites for Multitemporal Analysis ..... 343
    - 7.3.2.1 Multitemporal Matching..... 343
    - 7.3.2.2 Radiometric Calibration ..... 345
  - 7.3.3 Methods for Seasonal Analysis ..... 346
  - 7.3.4 Change Detection Techniques..... 350
    - 7.3.4.1 Multitemporal Color Composites ..... 351
    - 7.3.4.2 Image Differencing..... 353
    - 7.3.4.3 Multitemporal Ratios ..... 354
    - 7.3.4.4 Principal Components ..... 354
    - 7.3.4.5 Regression Analysis..... 355
    - 7.3.4.6 Change Vector Analysis ..... 355
    - 7.3.4.7 Defining Change Thresholds ..... 359
    - 7.3.4.8 Multitemporal Analysis of Classified Images..... 360
- 7.4 Analysis of Spatial Properties ..... 363
  - 7.4.1 Remote Sensing and Landscape Ecology..... 363

7.4.2	Spatial Metrics for Interval-Scale Images.....	365
7.4.2.1	Global Metrics for Continuous Data.....	365
7.4.2.2	Local Metrics for Continuous Data .....	368
7.4.3	Spatial Metrics for Classified Images .....	369
7.4.3.1	Global Metrics for Classified Data .....	371
7.4.3.2	Local Metrics for Classified Data.....	372
7.4.4	Landscape Structural Dynamics .....	374
7.5	Review Questions .....	374
<b>Chapter 8</b>	<b>Validation .....</b>	<b>379</b>
8.1	Relevance of Validating Results.....	379
8.2	Sources of Error.....	381
8.2.1	Sensor Limitations .....	381
8.2.2	Method of Analysis .....	381
8.2.3	Landscape Complexity .....	382
8.2.4	Verification Process.....	383
8.3	Methods to Estimate Accuracy .....	386
8.4	Sampling Design .....	387
8.4.1	Error Distribution.....	388
8.4.2	Sampling Unit.....	388
8.4.3	Sampling Strategies.....	388
8.4.4	Sample Size .....	390
8.5	Gathering Information.....	392
8.6	Validating Interval-Scale Variables.....	393
8.7	Validating Classified Images.....	394
8.7.1	Confusion Matrix .....	394
8.7.2	Global Accuracy.....	395
8.7.3	User and Producer Accuracy.....	398
8.7.4	Kappa Statistic.....	399
8.7.5	Normalizing the Confusion Matrix.....	401
8.7.6	Validation of Binary Classes.....	403
8.7.7	Verification in Multitemporal Analysis.....	405
8.8	Review Questions .....	406
<b>Chapter 9</b>	<b>Remote Sensing and Geographic Information Systems.....</b>	<b>409</b>
9.1	Trends in GIS and Remote Sensing Development.....	409
9.2	GIS as Input for RS Interpretation .....	411
9.3	RS as Input for GIS .....	412
9.3.1	Availability of Geographic Information.....	412
9.3.2	Generation of Input Variables .....	413
9.3.3	Updating the Information.....	414
9.4	Integration of Satellite Images and GIS .....	415
9.5	Review Questions .....	417

Contents	xiii
<b>Appendix</b> .....	419
<b>References</b> .....	423
<b>Index</b> .....	459