
Contents

Foreword	xi
Acronyms	xv
Introduction	xxxix
Nicolas BAGHDADI and Mehrez ZRIBI	
Chapter 1. Synthetic Aperture Radar Imaging	1
Laurent FERRO-FAMIL and Eric POTTIER	
1.1. Introduction.	1
1.2. Introduction to synthetic aperture radar (SAR) imaging	3
1.2.1. Objectives of a coherent radar measurement.	3
1.2.2. Range focusing	16
1.2.3. 2D imaging by synthetic aperture	24
1.3. Characteristics of SAR images	36
1.3.1. Radiometry	36
1.3.2. Geometry.	49
1.3.3. Correction and calibration of SAR images	57
1.4. Key points	61
1.5. Bibliography	62
Chapter 2. SAR Imaging using Coherent Modes of Diversity: SAR Polarimetry, Interferometry and Tomography	67
Laurent FERRO-FAMIL and Eric POTTIER	
2.1. Introduction.	67
2.2. SAR polarimetry.	69

2.2.1. Introduction to radar polarimetry: formalism, descriptors and polarimetric operators	69
2.2.2. Characterization of the polarimetric response of environments: polarimetric decompositions	85
2.2.3. A few applications using polarimetric SAR images.	105
2.3. An introduction to SAR interferometry and tomography	123
2.3.1. Principle of topography measurement through the SAR interferometry	123
2.3.2. Polarimetric SAR interferometry.	127
2.3.3. Differential SAR interferometry	133
2.3.4. SAR tomography	136
2.4. Key points	140
2.5. Bibliography	141
Chapter 3. The Principles of DTM Reconstruction from SAR Images	149
Jean-Marie NICOLAS and Florence TUPIN	
3.1. Introduction.	149
3.2. Geometry of SAR images	150
3.2.1. Time cells, range cells and ground cells	150
3.2.2. Artifacts linked to ground elevation	154
3.3. The SAR image spectrum	156
3.4. Registration of SAR images	159
3.5. Radargrammetry and interferometry	161
3.5.1. Acquisition geometry with two sensors.	161
3.5.2. Radargrammetry	162
3.5.3. Interferometry	164
3.6. The limitations of interferometry	166
3.6.1. Critical basis.	166
3.6.2. Altitude of ambiguity	168
3.6.3. Interferogram filtering	168
3.6.4. Geometric and temporal coherence	170
3.6.5. Registration and “orbital” fringes	170
3.7. Conclusions.	171
3.8. Key points	172
3.9. Bibliography	172
Chapter 4. Principles of Radar Satellite Altimetry for Application on Inland Waters	175
Stéphane CALMANT, Jean-François CRÉTAUX and Frédérique RÉMY	
4.1. Introduction.	175
4.2. Radar altimetry measurements	181

4.3. Processing echoes, or retracking	183
4.4. Sloping measurements and different radar modes	188
4.4.1. Sloping measurements in LRM mode	188
4.4.2. SAR mode (Synthetic Aperture Radar)	191
4.4.3. SARIn mode	191
4.5. Propagation corrections (or atmospheric corrections)	193
4.5.1. Dry tropospheric correction ΔR_{dry}	194
4.5.2. Wet tropospheric correction ΔR_{wet}	195
4.5.3. Ionospheric correction ΔR_{ion}	196
4.6. Geophysical corrections	197
4.6.1. Tidal load	198
4.6.2. Atmospheric load	198
4.6.3. Hydrological load	198
4.6.4. Ocean tide	199
4.6.5. Polar tide	200
4.6.6. Earth tide	200
4.7. Altimetry biases	201
4.8. Selecting measurements	203
4.9. Choice of orbits in altimetry missions	205
4.10. Perspectives	208
4.11. Key points	209
4.12. Acknowledgments	210
4.13. Bibliography	210

**Chapter 5. Passive Low Frequency
Microwaves: Principles, Radiative
Transfer, Physics of Measurements 219**

Jean-Pierre WIGNERON and Yann KERR

5.1. Introduction	219
5.2. Radiometric measurement	221
5.2.1. Introduction	221
5.2.2. Reminders on a few principles of physics	221
5.2.3. Signal measured by a microwave radiometer	225
5.2.4. Disturbances because of anthropogenic radio frequency interference (RFI)	233
5.3. Modeling microwave emission on natural surfaces	234
5.3.1. Modeling the microwave emission of a vegetation cover	234
5.3.2. Modeling of soil emission	245
5.3.3. A summary model: L-band Microwave Emission of the Biosphere (L-MEB)	254
5.4. Main space missions (SMOS, SMAP, AMSR-E)	262
5.4.1. AMSR	265

5.4.2. SMOS.	266
5.4.3. SMAP.	270
5.4.4. Aquarius	270
5.5. Conclusions and perspectives	270
5.6. Key points	271
5.7. Bibliography	272
Chapter 6. Space Gravimetry Using GRACE Satellite Mission: Basic Concepts	285
Guillaume RAMILLIEN, Frédéric FRAPPART and Lucía SEOANE	
6.1. Introduction.	285
6.2. The GRACE spatial gravimetry mission.	287
6.2.1. Description of the principle of measurement.	287
6.2.2. The instruments on board	288
6.2.3. Temporal variations of mass on Earth.	288
6.2.4. Accuracy and spatial resolution expected for applications in continental hydrology.	290
6.3. Data from the GRACE spatial gravimetry mission	290
6.3.1. Level 2 solutions of the GRACE mission.	291
6.3.2. Converting water mass anomalies	294
6.3.3. Accuracy of the GRACE data	296
6.4. Perspectives	299
6.5. Key points	299
6.6. Bibliography	300
Chapter 7. The Reflected Global Navigation Satellite System (GNSS-R): from Theory to Practice	303
José DARROZES, Nicolas ROUSSEL and Mehrez ZRIBI	
7.1. Introduction	303
7.2. Available GNSS signals	304
7.2.1. An ever-effective ancestor: the GPS.	304
7.2.2. Transmitted signals.	307
7.2.3. The GALILEO system.	311
7.2.4. Other constellations	314
7.2.5. Positioning	316
7.2.6. Augmentation systems.	321
7.3. The GNSS-R measurement techniques	323
7.4. Reflectometry through opportunity signals	327
7.4.1. Geometry of multi-static systems	327
7.4.2. Coherent and incoherent scattering	329
7.4.3. Signal modeling.	331
7.4.4. Delay and Doppler	333

7.4.5. Observables obtained from airborne platforms	334
7.4.6. IPT	338
7.5. Platforms and constraints.	345
7.5.1. Fixed/ <i>in situ</i>	345
7.5.2. Airborne	346
7.5.3. Satellite.	349
7.6. Conclusions and perspectives	350
7.7. Key points	351
7.8. Bibliography	352
Chapter 8. Data Assimilation of Satellite Observations	357
Catherine OTTLÉ and Jean-François MAHFOUF	
8.1. Introduction.	357
8.2. General principles of data assimilation.	358
8.2.1. Basic concepts.	358
8.2.2. Optimal estimation	360
8.3. Kalman filters and variational approaches.	365
8.3.1. BLUE analysis	366
8.3.2. Kalman filters	367
8.3.3. Variational assimilation	370
8.4. Error modeling.	373
8.4.1. Observation error modeling.	374
8.4.2. Background error modeling.	376
8.5. Particle filters.	378
8.6. Conclusions and perspectives	379
8.7. Key points	380
8.8. Bibliography	381
Glossary	383
List of Authors	401
Index	403
Scientific Committee	407