

Contents

| | |
|----------------------|----------|
| Preface | page vii |
| List of acronyms | ix |
| List of main symbols | xi |

| | | |
|----------|----------------------------------------------------------------------------------|------------|
| 1 | Introduction | 1 |
| 1.1 | Background | 1 |
| 1.2 | Early ideas and observations | 1 |
| 1.3 | Tidal patterns | 3 |
| 1.4 | Meteorological and other non-tidal changes | 7 |
| 1.5 | Some definitions of common terms | 8 |
| 1.6 | Basic statistics of sea levels as time series | 11 |
| 2 | Sea-level measuring systems | 17 |
| 2.1 | The science of measurement | 17 |
| 2.2 | Datum definitions | 20 |
| 2.3 | Coastal instruments | 22 |
| 2.4 | Open-sea gauges | 30 |
| 2.5 | Data reduction | 31 |
| 2.6 | Data sources | 33 |
| 3 | Tidal forces | 36 |
| 3.1 | Gravitational attraction | 36 |
| 3.2 | The tidal forces: a fuller development | 40 |
| 3.3 | The Moon–Earth–Sun system | 44 |
| 3.4 | Tidal patterns | 49 |
| 3.5 | Extreme tidal forces | 53 |
| 4 | Tidal analysis and prediction | 60 |
| 4.1 | Non-harmonic methods | 61 |
| 4.2 | Harmonic analysis | 62 |
| 4.3 | Response analysis | 78 |
| 4.4 | Analysis of currents | 82 |
| 4.5 | Time zone conversion | 86 |
| 4.6 | Stability of tidal parameters | 87 |
| 4.7 | Tidal predictions | 89 |
| 5 | Tidal dynamics | 97 |
| 5.1 | The real world | 97 |
| 5.2 | Long-wave characteristics | 99 |
| 5.3 | Ocean tides | 105 |
| 5.4 | Shelf tides | 111 |
| 5.5 | Radiational tides | 122 |
| 5.6 | Internal tides | 124 |
| 5.7 | The yielding Earth | 126 |
| 5.8 | Are tides changing? | 129 |
| 6 | Shallow-water and coastal tides | 133 |
| 6.1 | Introduction: some observations | 133 |
| 6.2 | Hydrodynamic distortions | 133 |
| 6.3 | Representation by higher harmonics | 136 |
| 6.4 | Tidal currents | 139 |
| 6.5 | Tidal asymmetry | 143 |
| 6.6 | Tides in rivers | 144 |
| 6.7 | Energy budgets | 149 |
| 7 | Storm surges, meteotsunamis and other meteorological effects on sea level | 155 |
| 7.1 | Introduction | 155 |
| 7.2 | The depth-averaged (2-D) equations | 155 |
| 7.3 | Storm surges | 156 |
| 7.4 | Statistics of tidal residuals | 164 |
| 7.5 | Seiches | 165 |
| 7.6 | Meteotsunamis | 170 |
| 7.7 | Wave set-up and surf beat | 172 |
| 7.8 | Air pressure-related changes of sea level in the world ocean | 173 |
| 8 | Tsunamis | 189 |
| 8.1 | Introduction | 189 |
| 8.2 | Why tsunamis happen | 192 |
| 8.3 | Tsunami propagation across the ocean | 199 |
| 8.4 | Coastal shoaling and runup | 203 |
| 8.5 | Tsunami signals in sea-level and bottom pressure data | 206 |

Contents

| | | | |
|---------------------------------------------------------------|-----|----------------------------------------|----------------------------------------------------------------------------|
| 8.6 Sea-level and related technologies for tsunami monitoring | 207 | 12 Sea-level applications | 318 |
| 8.7 Tsunami further reading | 215 | 12.1 Design parameters | 318 |
| 9 Spatial variations in sea level | 223 | 12.2 Extreme conditions | 319 |
| 9.1 Introduction | 223 | 12.3 Coastal defences | 327 |
| 9.2 The International Terrestrial Reference Frame | 223 | 12.4 Lagoons and channels | 329 |
| 9.3 The Global Positioning System | 224 | 12.5 Power generation | 331 |
| 9.4 DORIS | 227 | 12.6 Emersion–submersion probabilities | 335 |
| 9.5 Satellites and the Mean Sea Surface | 227 | 12.7 Flood warning systems | 337 |
| 9.6 Satellites and the geoid | 233 | 12.8 Economics of coastal defences | 341 |
| 9.7 Models of the MSS, geoid and MDT | 240 | 13 Sea level and life | 345 |
| 9.8 A comment on epochs | 243 | 13.1 Introduction | 345 |
| 9.9 Towards a global vertical datum | 243 | 13.2 The Moon and us | 345 |
| 10 Mean sea-level changes in time | 252 | 13.3 Intertidal life | 346 |
| 10.1 Introduction | 252 | 13.4 Human development | 351 |
| 10.2 Sea-level data | 252 | 13.5 The sea-level present | 354 |
| 10.3 Mesoscale variability in sea level | 254 | 13.6 The sea-level future | 355 |
| 10.4 The seasonal cycle of MSL | 256 | | |
| 10.5 Pole tide | 259 | | |
| 10.6 Nodal tide | 261 | | |
| 10.7 Air pressure-related sea-level variability | 262 | | |
| 10.8 Large-scale patterns of interannual variability | 264 | | |
| 10.9 Long-term changes in sea level | 268 | | |
| 10.10 Understanding sea-level change | 276 | | |
| 10.11 Future rise in mean and extreme sea levels | 280 | | |
| 11 Sea-level changes in time to do with the solid Earth | 296 | | |
| 11.1 Introduction | 296 | Appendix A | <i>Basic hydrostatic and hydrodynamic equations</i> 361 |
| 11.2 Techniques for measuring vertical land movement | 296 | A.1 | <i>The hydrostatic equation</i> 361 |
| 11.3 Glacial Isostatic Adjustment | 301 | A.2 | <i>Conservation of mass</i> 361 |
| 11.4 Tectonic sea-level changes | 303 | A.3 | <i>The horizontal momentum equations</i> 361 |
| 11.5 Man-made crustal movements | 307 | Appendix B | <i>Currents</i> 363 |
| 11.6 Geophysical fingerprints of sea-level change | 308 | B.1 | <i>Analysis of currents</i> 363 |
| 11.7 Coastal processes | 309 | B.2 | <i>Current dynamics</i> 365 |
| | | Appendix C | <i>High and low water times and heights from harmonic constituents</i> 368 |
| | | Appendix D | <i>Theoretical tidal dynamics</i> 370 |
| | | D.1 | <i>Long progressive waves, no rotation</i> 370 |
| | | D.2 | <i>Standing waves</i> 372 |
| | | D.3 | <i>Long waves on a rotating Earth</i> 373 |
| | | D.4 | <i>Co-tidal and co-amplitude lines</i> 374 |
| | | Appendix E | <i>Legal definitions in the coastal zone</i> 376 |
| | | Glossary | 380 |
| | | Index | 389 |