Physical Principles of Remote Sensing

Third Edition

Fully updated and with significant new treatments of photography, laser profiling and image processing, the third edition of this popular textbook covers a broad range of remote sensing applications and techniques across the earth, environmental and planetary sciences. It focusses on physical and mathematical principles, giving students a deeper understanding of remote sensing systems and their possibilities, while remaining accessible to those with less mathematical training by providing less technical summaries of quantitative topics.

Key features

- Boxed examples and additional photos engage students and show them how the theory relates to real-world applications.
- Numerous colour images bring the subject to life.
- Section summaries, review questions and additional problems allow students to check their understanding of key concepts and practise handling real data for themselves.
- Review questions link out to supplementary online material, which includes freely available software, practical exercises and animations.

W. G. Rees is a Senior Lecturer at the Scott Polar Research Institute, University of Cambridge, where he has taught and researched in the field of remote sensing for over 20 years. He has been active in developing and applying remote sensing methods to the mapping and monitoring of the polar regions, having conducted fieldwork in arctic regions of Europe and Asia, and in Svalbard. For the past few years he has been joint coordinator of PPS Arctic, a major programme to investigate the characteristics and behaviour of the arctic treeline as part of the International Polar Year, and he is also a member of the ISPRS (International Society for Photogrammetry and Remote Sensing) working group on LiDAR. Dr Rees has published several books on remote sensing, including the first and second editions of *Physical Principles of Remote Sensing* (1990, 2001, Cambridge University Press), *The Remote Sensing Data Book* (1999, Cambridge University Press) and *Remote Sensing of Glaciers* (with P. Pellikka, 2010, Taylor & Francis). He was made a Fellow of the Institute of Physics in 1996 and is a member of the Photogrammetry and Remote Sensing Society.

"This is a welcome new edition of a popular text, with wonderful color illustrations. The author helps students digest the principles by adding useful summaries and review questions. A practical improvement for students and instructors is the addition of the rich suite of online resources, which greatly add to the book's appeal."

Dr. Farouk El-Baz
Director, Center for Remote Sensing, Boston University

"Rees' new edition of his popular remote sensing textbook is written in an easy-to-follow style, but doesn't neglect the mathematical underpinnings. It covers principles related to all the key wavelength regions, and such diverse topics as photogrammetry, atmospheric sounding and multispectral imaging. Including coverage of applications on land, in the atmosphere and oceans, it represents an excellent resource for students and practitioners alike."

Professor Martin Wooster
Environmental Monitoring & Modelling Research Group, Kings College London

"The third edition of this well known, highly respected and authoritative textbook contains a wealth of new material that captures advances in optical and microwave sensor systems and applications. University teachers will be delighted that the format remains the same; theory and technical detail are explained in clear language and supported by excellent diagrams and figures. The book incorporates good pedagogic principles that incorporate summaries for each topic, additional text boxes to help guide students not familiar with certain theoretical concepts, and review questions with problems to assist teachers to set extension exercises. The book uses excellent examples, many of which are new in this edition, that clearly demonstrate why remote sensing data from a very wide range of sensors and platforms has such an impact on science and society today. Every student of remote sensing, whatever their level, and every library should have a copy of this excellent book."

Professor Daniel Donoghue
Department of Geography, Durham University

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W. G. REES

Scott Polar Research Institute
University of Cambridge

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as always

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PREFACE

There are many books that explain the subject of remote sensing to those whose backgrounds are primarily in the environmental sciences. This is an entirely reasonable fact, since they continue to be the main users of remotely sensed data. However, as the subject grows in importance, the need for a significant number of people to understand not only what remote sensing systems do, but how they work, will grow with it. This was already happening in 1990, when the first edition of *Physical Principles of Remote Sensing* appeared, and since then increasing numbers of physical scientists, engineers and mathematicians have moved into the field of environmental remote sensing. It is mainly for such readers that this book, like its previous editions, has been written. That is to say, the reader for whom I have imagined myself to be writing is educated to a reasonable standard (although not necessarily to first degree level) in physics, with a commensurate mathematical background. I have however found it impossible to be strictly consistent about this, because of the wide range of disciplines within and beyond physics from which the material has been drawn, and I trust that readers will be understanding when they find the treatment either too simple or over their heads.

This book attempts to follow a logical progression, more or less following the flow of information from the remotely sensed object to the user of the data. The first four chapters lay the general foundations. Chapter 1 sets the subject in context. Chapter 2 is a non-rigorous treatment of electromagnetic wave propagation in free space, which can be regarded as a compendium of necessary results. It will represent, I hope, mostly revision to most readers, although it assumes little or no previous knowledge of Fourier transforms or of Fraunhofer diffraction theory. Chapter 3 discusses the interaction of electromagnetic radiation with smooth and rough surfaces and with inhomogeneous materials such as soil and snow, and Chapter 4 discusses the interaction of radiation with the atmosphere and ionosphere. By this stage of the book, our information is, as it were, travelling upwards towards the sensor. Chapters 5 to 9 discuss the sensors themselves, beginning with the more familiar passive sensors and going on to consider active systems. These chapters explain, so far as is consistent with the level of the book, the functioning of the sensors, important operational constraints, and some of the more important applications derived from them. These chapters also include brief descriptions of real instruments on existing or forthcoming satellite missions. The platforms on which the sensors are supported are discussed in Chapter 10. After a short discussion of remote sensing from aircraft, the chapter devotes itself to satellite orbits. Finally, Chapter 11 presents an introduction to the data processing aspects of remote sensing, particularly digital image processing and analysis. An appendix contains tables of data frequently needed in remote sensing. A short list of problems or exercises is included at the end of most chapters. Most of these problems are reasonably straightforward (I have tried to indicate which are for 'enthusiasts'), designed to extend and consolidate the reader's understanding of the material. Some problems will require material from more than one chapter for

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their solution. The problems are of a more or less 'academic' format, many of them having originated as exercises for students.

It will perhaps be useful to indicate those features of the book that have been preserved from the second edition and those that are new. The underlying rationale has not changed. It has still been my intention to keep the book as short as possible, consistent with clarity, although this edition is significantly longer than the second because it includes new material. In particular, the treatment of stereophotography (Chapter 5), laser profiling (Chapter 8), synthetic aperture radar interferometry (Chapter 9), and digital image processing (Chapter 11) have all been significantly expanded. As before, the aim has been to teach principles of remote sensing rather than to present a lot of technical or engineering detail. However, the inclusion of brief discussions of real sensor systems or surveys of types of sensor, introduced in the second edition, has been continued, expanded and updated, particularly in Chapter 6, which deals with visible-wavelength and infrared systems. The book's bibliography has been brought up to date, although I have still attempted to keep it short enough so as not to overwhelm the reader with an enormous list of references. Some selection and omission has therefore been necessary, and I hope my colleagues will forgive me if my selection does not tally with theirs. One particular goal in compiling the bibliography has been to include enough recent references to allow the reader efficiently to find his or her way into the modern literature. As in the first edition, I have deliberately avoided the rigorous consistency in the use of *symbols* that demands that a given symbol be used to represent only a single physical quantity. Because of the wide scope of remote sensing, this would lead to an unforgivably confusing proliferation of symbols with many sub- and superscripts. Consistency of symbols is therefore confined to sections of the text that deal with a single topic, except for a few 'universal' symbols such as h for the Planck constant and ω for angular frequency, which are used throughout the book. SI units are used consistently, although a table in the appendix gives equivalents for some common non-SI units.

There are some other important changes in this edition. The number of illustrations has increased by about a third, with much greater use of colour. This is especially valuable in the understanding of satellite imagery. As aids to understanding the ideas presented in the book, each chapter apart from the introductory Chapter 1 now includes more or less non-technical summaries and a set of review questions. The summaries, which are presented in boxes at the end of each major section, can be read consecutively as a 12 000 word outline of the whole book, but are probably most usefully read where they have been placed, at the end of each section, where they can be used to check the reader's understanding of the main points without getting lost in mathematical detail. The review questions can also be used as an aid to comprehension of the material: when teaching university courses based on some of this material I have found it helpful to ask students to prepare five-minute responses to such review questions, which they can then present to the class.

One difficulty that I found in the first two editions of the book was that of clearly explaining the behaviour of some time-dependent phenomena. Examples of this include the propagation of electromagnetic radiation, the orbit of a satellite around the Earth, and the manner in which the pulse of radiation from a radar altimeter interacts with a rough surface, although there are others. I have developed some computer animations to illustrate such phenomena, and these are accessible on the book's website – another innovation for this edition. They are indicated by a mouse-button icon in the margin.

The website also provides hints and solutions to the problems, useful links, and a repository of computer programs that can be used to explore some of the ideas in the book. The problems included at the end of each chapter are supplemented, in the website, by suggested practical exercises. Particular emphasis has been placed on exercises designed to consolidate the reader's understanding of the main ideas in Chapter 11. It is expected that all of the web-based material will evolve over time.

This book arose from a course of undergraduate lectures delivered first at the Scott Polar Research Institute, and later at the Cavendish Laboratory, both in the University of Cambridge. I am grateful to both departments for letting me try out my ideas. Many people are owed thanks for their contributions to the writing of the first edition. It is difficult to single out individuals, but I particularly wish to thank Andrew Cliff, Bernard Devereux, Michael Gorman, Christine Rees and Michael Rycroft. Subsequently I have developed some of the concepts in the book for teaching to audiences with a wider range of background knowledge than the book's intended readership, including undergraduates in the Department of Geography at the University of Cambridge and at the Geography Faculty of Moscow State University, and children as young as six years old. Much of the credit for any improvements that I may have made to the book since the first edition lies with the constructive criticisms of the users and reviewers of the first edition and of the many graduate and undergraduate students who I have had the pleasure of working with since 1990, as well as with my professional colleagues. In particular, I thank Neil Arnold, Olga Tutubalina and Sophie Weeks. As always, Cambridge University Press has provided advice and encouragement whenever it was needed.

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