Remote Sensing of Landscapes with Spectral Images

Spectral images, especially those from satellites such as Landsat, are used worldwide for many purposes, ranging from monitoring environmental changes and evaluating natural resources to military operations. In a significant departure from standard remote-sensing texts, this book describes how to process and interpret spectral images using physical models to bridge the gap between the engineering and theoretical sides of remote sensing and the world that we encounter when we put on our boots and venture outdoors.

Remote Sensing of Landscapes with Spectral Images is designed as a textbook and reference for graduate students and professionals in a variety of disciplines including ecology, forestry, geology, geography, urban planning, archeology, and civil engineering, who want to use spectral images to help solve problems in the field. The emphasis is on the practical use of images rather than on theory and mathematical derivations, although a knowledge of college-level physics is assumed. Examples are drawn from a variety of landscapes and interpretations are tested against the reality seen on the ground. The reader is led through analysis of real images (using figures and explanations), and the examples are chosen to illustrate important aspects of the analytic framework, rather than simply how specific algorithms work.

This book is supplemented by a website hosting digital color versions of figures in the book as well as ancillary color images (www.cambridge.org/9780521662215).

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A Physical Modeling Approach

John B. Adams
and
Alan R. Gillespie
Department of Earth and Space Sciences
University of Washington

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To Caryl and Karen

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About the authors

John B. Adams

John Adams worked on early geological exploration of the Moon, planets, and asteroids, and was instrumental in developing reflectance spectroscopy as a remote-sensing method for mineral identification. As a member of the scientific team that studied the first lunar samples, he demonstrated that Earth-based telescopic spectra could be used to identify and map rock types on the Moon. He has used spectroscopy-based remote sensing of Earth to study geomorphic processes in arid regions and to interpret changes in land use in temperate and tropical landscapes around the world. Adams established the Remote Sensing Laboratory at the University of Washington in Seattle in 1975. He presently is Emeritus Professor in the Department of Earth and Space Sciences at the University of Washington. He spends as much time as possible in the North Cascade Mountains of Washington.

Alan R. Gillespie

Alan Gillespie is a Professor of Earth and Space Sciences at the University of Washington in Seattle, where he has been since 1987. He has been involved with remote sensing since joining the Mars Mariner project at Caltech's Jet Propulsion Laboratory late in 1969. With the launch of ERTS-1, Gillespie switched to terrestrial remote sensing, focusing first on image processing and then on applications, with emphasis on the thermal infrared. He has been a member of the US Terra/ASTER team since 1991, and is responsible for the temperature/emissivity separation algorithms and standard products. Gillespie is also a glacial geologist with a strong interest in paleoclimate. He graduated from Caltech in 1982 with a Ph.D. in geology and a thesis on the glacial history of the Sierra Nevada. Since 1991 he has been using remote sensing and field studies to elaborate the regional variations in the glacial history of central Asia. With Barry Siegal, Gillespie contributed to and edited *Remote Sensing in Geology* (1980). Gillespie is currently the editor of *Quaternary Research*.

Preface

This book is about how to process and interpret spectral images of landscapes. It is designed for students and professionals in a variety of disciplines who want to do hands-on computer analysis of spectral images to solve problems in the field. The term "landscape" conveys the idea of a part of the land surface that we can see from a vantage point on the ground. It is at landscape scales, rather than at regional or global scales, that we are able to make the most convincing links between remote-sensing measurements and the materials and objects that we see on the ground. In this book, the approach to the study of spectral images at this scale is unconventional. Most other texts on spectral remote sensing emphasize radiative transfer, engineering aspects of remote-sensing systems, and algorithms for manipulating digital images. Indeed, these subjects already have been covered so well that we see no reason to replicate this work. We have taken a new approach that focuses on the intersection of photo interpretation and spectroscopic modeling.

There are practical reasons for shifting the emphasis to physically based models. People in a variety of disciplines use spectral images to obtain information that is important for their landscape-scale projects. For many of these projects it is essential that the extracted information is correct and that it makes sense in the given context. Investigators also want spectral images to give them new insights into materials and processes so that there is the possibility for discovery. However, text books that treat the fundamentals of remote-sensing science and engineering rarely take the next step to explain how actually to go about interpreting spectral images. In our experience, students who have taken the basic remote-sensing courses, when faced with a practical problem that requires interpreting the data, often express the same frustration: "What do you actually DO?" they ask. They know how to invoke algorithms, but they do not yet have a clear understanding of how to tease the desired information out of the data. More importantly, many are not yet familiar with the spectral properties of materials on the ground.

Our objective is to bridge the gap between the more theoretical and engineering side of remote-sensing science and the world that we encounter when we put on our boots and venture into the field. A basic premise is that remotely sensed spectral images are a proxy for observing directly on the ground. Therefore, to interpret spectral images we need to understand the spectral behavior of natural materials, and we need to be able to think like field investigators. This is a tall order, and it may stretch the borders of most remote-sensing curricula. The payoff is a new ability to extract information from spectral images. By applying physical models to remote sensing at landscape scales, we also enhance our ability to "scale up" interpretations to regional and global scales.

To achieve our objectives, we have limited the scope of the book to spectral images in visible and near-infrared wavelengths, and, to a lesser extent, to thermal-infrared images. This emphasis reflects the reality that the most readily available spectral images to support field work are the ones that are being most widely used. Many of our examples are based on Landsat Thematic Mapper (TM) images of areas that we personally have studied on the ground. Landsat images happen to be ideal to illustrate the methods that we discuss, and they comprise a nearly continuous (and under-utilized) 30-year global data base for on-going studies of environmental and land-use changes. The field of view of Landsat TM images is large enough to encompass most field-study areas, and the pixel footprint is small enough to recognize where you are on the ground. The six visible and near-infrared TM Bands provide useful spectral information, but the quantity of data is relatively easily managed. Nevertheless, the analytical and interpretive approach that we describe applies to all spectral imaging systems, including imaging spectrometers having hundreds of spectral channels.

In order to reach a broad, multidisciplinary audience, our explanations are light on equations and heavy on visual examples. The book is suitable as a text for classes in remote sensing and as a professional reference; however, we do assume that our readers already have some background in the fundamentals of remote sensing. For those who need to brush up, there are several excellent basic texts in print. We elaborate on certain topics that only are treated briefly, or are omitted from most texts, and that we feel are essential for image interpretation. These topics include spectral contrast, basic spectral components of scenes, spectral unmixing, the application of fraction images, detectability of targets, and physically based thematic mapping.

Illustrations

The website (www.cambridge.org/9780521662214) hosts digital color versions of the figures in the book and allows us to include more color pictures than the ones in the color plates that are bound within the text. For those who do not have convenient access to a computer when they are reading, a black and white version of each color figure on the Web, with its caption, is included in the text. In addition, the website has reference images that elaborate on the properties of four Landsat TM images that are used frequently in the illustrations.

We constructed a 20 × 20-pixel synthetic image to assist in explaining some of the methods for exploring spectral images. A particular advantage of the synthetic image is that it allows us to compare the results of various algorithms and operations. First, we know exactly how the image was constructed; therefore, we already know the correct answers, and can evaluate how well various algorithms and image-processing techniques work. Second, the simple pattern of the image avoids the contextual distractions of real images of landscapes. The structure of the synthetic image is defined in Chapter 3.

Terms and definitions

Remote sensing as a discipline has accumulated a substantial amount of jargon. With those of you in mind who care more about applications than about remote-sensing technology, we have attempted to minimize the jargon and to be careful about how terms are used. Many of the technical terms in the text are defined in marginal notes and in the Glossary.

Acknowledgments

Ideas for organizing materials and for explaining arcane aspects of remote sensing were tempered in the forge of various classes taught by both authors at the University of Washington over the past 25 years. We especially benefited from the wide range of backgrounds of our students in these classes, both beginning and advanced. In addition to geologists and geophysicists we commonly instructed, and learned from, students in forestry, geography, urban planning, oceanography, fisheries, botany, archeology, civil engineering, astronomy, and statistics.

Our approach to spectral imaging has been strongly influenced by our colleagues and graduate students in the W. M. Keck Remote Sensing Laboratory at the University of Washington who have worked with us over the years on a variety of projects. Research topics ranged from the composition of the surfaces of the Moon and Mars, to processes in terrestrial deserts, to changes in Amazon and northwest forests. The Department of Geological Sciences (now the Department of Earth and Space Sciences), the home for the Remote Sensing Laboratory, provided support and encouragement over the years to what must have appeared at times to be a maverick unit that crossed all disciplinary lines.

We have benefited enormously from the exchange of ideas with our many colleagues across the nation and around the world. We owe a special debt to Milton Smith, who for many years was a key part of the intellectual brew of the laboratory, and with whom we shared the excitement and frustrations of developing spectral-mixture analysis. In preparing the book, we benefited from discussions with Stephanie Bohlman, Roger Clark, Don Sabol, and Robin Weeks. Thanks to Elsa Abott for finding long-lost images, files and references. Helpful reviews of the manuscript were made by Caryl Campbell, Laura Gilson, Karl Hibbitts, Jim Lutz, and Amit Mushkin. Technical and facilities support was provided by Bill Gustafson, Tom McCord, Marty Nevdahl, Sally Ranzau, and Karin Stewart-Perry.

Special thanks are due to Laura Gilson who drafted the illustrations, and who kept us organized throughout the long process of writing and revisions. Her skills in technical illustration and image processing emboldened us to produce a much more ambitious book than we originally visualized.

We are grateful to the W. M. Keck Foundation for grants to the Remote Sensing Laboratory over a period of several years that enabled us to explore innovative ways of extracting information from spectral images, and in particular, spectral-mixture analysis and related techniques. In an era when most research grants are awarded with the expectation of quick results, it has been difficult to stay focused on the hard problems that require several years, if not decades, of work. The long view and light hand of the W. M. Keck Foundation has been of immense value in developing and testing our ideas about spectral remote sensing.

We also acknowledge the National Aeronautics and Space Administration for supporting various research projects over many years. This support, along with funding from other governmental and private organizations not only facilitated research, but it enriched the experiences of our students, and provided the crucible out of which this book emerged.

Our thanks to Matt Lloyd, Susan Francis and Wendy Phillips at Cambridge University Press for guiding us through the administrative and technical thicket that lies between a manuscript and a published book. And special thanks to Zoë Lewin, our excellent copy editor, who gently made us realize that we were not quite through yet, and that there always is room for improvement.