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ADVANCED REMOTE SENSING

TERRESTRIAL INFORMATION EXTRACTION AND
APPLICATIONS



ADVANCED REMOTE SENSING

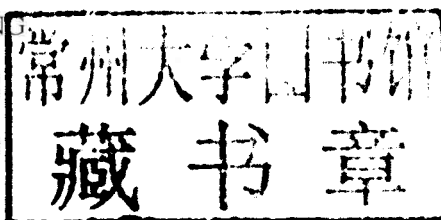
Terrestrial Information Extraction and Applications

Edited by

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Foreword

The Symposium on Quantitative Retrieval Algorithms in Remote Sensing was held in the summer of 2010 at Beijing Normal University. It was chaired by Professors Shunlin Liang and Xiaowen Li. During the Symposium, I stressed the roles of geography and remote-sensing science in the process of globalization. In the twenty-first century, world development has taken on three new characteristics: a constantly developing knowledge economy, constantly progressing globalization, and a widespread sustainable development theory. Since Earth science focuses on the relationships between human beings and the Earth's environment, it will significantly influence studies on the globalization process and sustainable development. For this reason, Earth science research in China should establish a much broader global outlook and extend its research perspective worldwide. Scientists should be much more concerned about global issues, multidisciplinary developments, and quantitative methods in the field of Earth science research.

Remote sensing is an important method of Earth observation. Satellite sensors can constantly observe the Earth's surface, and, with the development of remote-sensing science, it has become an important mechanism to determine spatial and temporal land-surface information quantitatively based on radiative transfer theory. High-level remote-sensing products are

urgently needed to meet global changes and for many other applications. Generating these high-level products is challenging, however, and has become a hot research topic. Remote-sensing scientists, especially the young scientists among them, are fully aware of this and have accordingly paid more attention to quantitative methodology. Therefore, they are more eager to understand fundamental principles and practical algorithms.

Professors Xiaowen Li and Shunlin Liang are long-term explorers in the research field of quantitative remote sensing. They are not only world-known scientists but also tutors and friends trusted by many young scholars. Their most ardent wish is to satisfy the need of readers, especially young students, for knowledge of quantitative remote sensing.

To meet the needs of scientists and graduate students, Professors Shunlin Liang, Xiaowen Li, and Jindi Wang secured the collaboration of a group of scientists engaged in the frontiers of remote sensing in producing this book two years after the 2010 Symposium. The present volume introduces remote-sensing systems, remote-sensing models, the inversion algorithms of nearly 20 land-surface variables, and existing global products, all of which are state of the art. The book offers an extensive resource and reference that will help readers understand quantitative remote-sensing principles, communicate more effectively with other

Earth science researchers and promote the quantitative applications of remote sensing.

This book will be of significant value to both students and scientists worldwide, helping to promote better understanding of quantitative remote sensing and contributing to the further development of Earth science in the twenty-first century.

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Preface

As the technology of remote sensing has advanced over the last two decades, the scientific potential of the data that it produces has greatly improved. To better serve society's needs, the immense amounts of aggregated satellite data need to be transferred into high-level products in order to improve the predictive capabilities of global and regional models at different scales and to aid in decision making through various decision support systems. A general trend is that the data centers are distributing more high-level products rather than simply the raw satellite imagery.

An increasing number of researchers from a diverse set of academic and scientific disciplines are now routinely using remotely sensed data products, and the mathematical and physical sophistication of the techniques used to process and analyze these data have increased considerably. As a result, there is an urgent need for a reference book on the advanced methods and algorithms that are now available for extracting information from the huge volume of remotely sensed data, which are often buried in various journals and other sources. Such a book should be highly quantitative and rigorously technical; at the same time, it should be accessible to students at the upper undergraduate and first-year graduate student level.

To meet this critical demand, we have identified and organized a group of active research scientists to contribute chapters and sections drawn from their research expertise. Although this is an edited volume with multiple authors,

it is well designed and integrated. The editors and authors have made great efforts to ensure the consistency and integrity of the text.

In addition to the introductory chapter, this book consists of five parts: (1) data processing methods and techniques; (2) estimation of land-surface radiation budget components; (3) estimation of biophysical and biochemical variables; (4) estimation of water cycle components; and (5) high-level product generation and application demonstrations. The titles and authors of the individual chapters are as follows:

Chapters	Titles	Authors
1	A Systematic View of Remote Sensing	S. Liang, J. Wang, B. Jiang
PART 1 Data Processing Methods and Techniques		
2	Geometric Processing and Positioning Techniques	X. Yuan, S. Ji, J. Cao, X. Yu
3	Compositing, Smoothing, and Gap-Filling Techniques	Z. Xiao
4	Data Fusion	J. Zhang, J. Yang
5	Atmospheric Correction of Optical Imagery	X. Zhao, X. Zhang, S. Liang
PART 2 Estimation of Surface Radiation Budget Components		
6	Incident Solar Radiation	X. Zhang, S. Liang
7	Broadband Albedo	Q. Liu, J. Wen, Y. Qu, T. He, X. Zhang

(Continued)

Chapters	Titles	Authors
8	Land-Surface Temperature and Thermal Infrared Emissivity	J. Cheng, H. Ren
9	Surface Longwave Radiation Budget	W. Wang
PART 3 Estimation of Biophysical and Biochemical Variables		
10	Canopy Biochemical Characteristics	Z. Niu, C. Yan
11	Leaf Area Index	H. Fang, Z. Xiao, Y. Qu, J. Song
12	Fraction of Absorbed Photosynthetically Active Radiation by Green Vegetation	W. Fan, X. Tao
13	Fractional Vegetation Cover	G. Yan, X. Mu, Y. Liu
14	Vegetation Height and Vertical Structure	G. Sun, Y. Pang, W. Ni, W. Huang, Z. Li
15	Above-Ground Biomass	G. Sun, W. Sun, S. Liang, Z. Zhang, E. Chen
16	Vegetation Production in Terrestrial Ecosystems	W. Yuan, Z. Chen
PART 4 Estimation of Water Balance Components		
17	Precipitation	Y. Liu, Q. Fu, X. Zhao, C. Dou
18	Terrestrial Evapotranspiration	K. Wang, R. Dickinson, Q. Ma
19	Soil Moisture Contents	S. Liang, B. Jiang, T. He, X. Zhu
20	Snow Water Equivalence	L. Jiang, J. Du, L. Zhang, J. Shi, J. Pan, C. Xiong
21	Water Storage	Y. Liu, P. Song

Chapters	Titles	Authors
PART 5 Production Generation and Application Demonstrations		
22	High-Level Land Product Integration	D. Wang
23	Production and Data Management Systems	S. Liu, X. Zhao
24	Land-Cover and Land-Use Changes	X. Zhu, S. Liang, B. Jiang

Chapter 1 presents introductory material and provides an overview of the book. From the system perspective, it briefly describes the essential components of the remote-sensing system, ranging from platforms and sensors, modeling approaches, and information extraction methods to applications.

Part 1 includes four chapters on data processing. Chapter 2 is the only chapter that presents the methods and techniques for handling geometric properties of remotely sensed data. These include the calibration of systematic errors, geometric correction, geometric registration, digital terrain model generation, and digital ortho-image generation.

Chapter 3 seeks to reconstruct spatial and temporal continuous high-quality imagery. As the temporal resolution of satellite observations greatly increases, images are more often contaminated by clouds and aerosols that partially or completely block the surface information. Two groups of techniques are presented. The first group deals with composite methods for aggregating the fine temporal resolution (say, daily) to the coarse resolution (say, weekly or monthly), and the second discusses smoothing and gap-filling methods to eliminate the impacts of clouds and aerosols at the same temporal resolution.

Chapter 4 introduces the basic principles and methods of data fusion for integrating multiple data sources on the pixel basis, which have

different spatial resolutions, and are acquired from different spectra (optical, thermal, microwave). This chapter focuses mainly on low-level data products. (The methods for integrating high-level products are introduced in Chapter 22.)

Chapter 5 introduces methods for correcting the atmospheric effects of aerosols and water vapor on the optical imagery. Other atmospheric correction methods are discussed in Chapter 8 for thermal-IR data and in Part 4 for microwave data.

Part 2 focuses on estimation of surface radiation budget components. The surface radiation budget is characterized by all-wave net radiation (R_n) that is the sum of shortwave (S_n) and longwave (L_n) net radiation

$$\begin{aligned} R_n &= S_n + L_n = (s\downarrow - s\uparrow) + (L\downarrow - L\uparrow) \\ &= (1 - \alpha)S\downarrow + (L\downarrow - L\uparrow) \end{aligned}$$

where $S\downarrow$ is the downward shortwave radiation (discussed in Chapter 6), $S\uparrow$ is the upward shortwave radiation, α is the surface shortwave albedo (discussed in Chapter 7), $L\downarrow$ is the downward longwave radiation, and $L\uparrow$ is the upward longwave radiation. Longwave net radiation (L_n) can be also calculated by

$$L_n = \varepsilon L\downarrow - \varepsilon \sigma T_s^4$$

where σ is the Stefan-Boltzmann constant, ε is surface thermal broadband emissivity, and T_s is surface skin temperature. Estimation of ε and T_s is discussed in Chapter 8, and $L\downarrow$ and L_n are covered in Chapter 9.

Part 3 focuses on the estimation of biochemical and biophysical variables of plant canopy. Chapter 10 introduces the various methods for estimating plant biochemical variables, such as chlorophyll, water, protein, lignin and cellulose. The biophysical variables discussed in this book include leaf area index (LAI) in Chapter 11, the fraction of absorbed photosynthetically active radiation by green vegetation (FPAR) in Chapter 12, fractional vegetation cover in Chapter 13,

vegetation height and vertical structure in Chapter 14, above-ground biomass in Chapter 15, and vegetation production in terms of gross primary production (GPP) and net primary production (NPP) in Chapter 16. Various inversion methods are introduced in this part, including optimization methods (Section 11.3.2), neural networks (Sections 11.3.3, 13.3.3 and 15.3.4), genetic algorithms (Section 11.3.4), Bayesian networks (Section 11.3.5), regression tree methods (Section 13.3.3), data assimilation methods (Section 11.4) and look-up table methods (Section 11.3.6). Part 3 also discusses multiple data sources besides optical imagery, such as Synthetic Aperture Radar (SAR) and Light Detection and Ranging (Lidar), and polarimetric InSAR data.

Part 4 is on estimation of water balance components. A general water balance equation is expressed by:

$$P = Q + E + \Delta S$$

where P is precipitation (discussed in Chapter 17), Q is runoff that is currently difficult to estimate from remote sensing, E is evapotranspiration (discussed in Chapter 18), and ΔS is the change in storage to which three chapters are related: soil moisture in Chapter 19, snow water equivalence in Chapter 20, and surface water storage in Chapter 21. In addition to optical and thermal data, microwave data are dealt with extensively in all chapters except in Chapter 18. The gravity data with the GRACE data are also briefly introduced in Chapter 21.

Part 5 deals with high-level product generation, integration, and application. Chapter 22 presents different methods for integrating high-level products of the same variable (e.g., LAI) that may be generated from different satellite data or different inversion algorithms. The data fusion methods for integrating low-level products are discussed in Chapter 4. Chapter 23 describes the typical procedures for producing high-level products from low-level satellite data and for developing a data management

system that is used for effectively handling a large volume of satellite data. The last chapter demonstrates how remote-sensing data products can be used for land-cover and land-use change studies, particularly on mapping the extent of three major land-use types (urban, forest, and agriculture), detecting changes in these land-use types, and evaluating the environmental impacts of these land-use changes.

One important feature of this book is its focus on extracting land-surface information from satellite observations. All relevant chapters follow the same template: introduction to basic concepts and fundamental principles, review of practical algorithms with a comprehensive list of references, detailed descriptions of representative algorithms and case studies, surveys of current products, spatiotemporal variations of

the variable, and identification of future research directions. The book includes almost 500 figures and tables, as well as 1700 references.

This book can serve as a text for upper-level undergraduate and graduate students in a variety of disciplines related to Earth observation. The entire book may be too lengthy for a one-semester or one quarter class, but most chapters in Parts 2–5 are relatively independent, and using a subset of them will be useful in such classes.

The text can also serve as a valuable reference book for anyone interested in the use and applications of remote-sensing data. Ideally, those using this book will have taken an introductory remote-sensing course, but we have written it at such a level that even those who have had little or no prior training in remote sensing can easily understand the overall development of this field.

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Shunlin Liang, Xiaowen Li, Jindi Wang

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