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978-0-521-51633-4 — Subsurface Fluid Flow and Imaging
Donald Wyman Vasco , Akhil Datta-Gupta
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SUBSURFACE FLUID FLOW AND IMAGING

The practice of imaging has grown tremendously over the past few decades. At the same time, understanding fluid flow at depth has become increasingly important to activities such as hydrocarbon production, groundwater exploitation, environmental remediation, and sequestration of greenhouse gases.

This book introduces methodologies for subsurface imaging based upon asymptotic and trajectory-based methods for modeling fluid flow, transport, and deformation. It describes trajectory-based imaging and inversion from its mathematical formulation, through the construction and solution of the imaging equations, to the assessment of the accuracy and resolution associated with the image. Unique in its approach, it provides a unified framework for the complete spectrum of physical phenomena from wave-like hyperbolic problems to diffusive parabolic problems and non-linear problems of mixed character. The practical aspects of imaging, particularly efficient and robust methods for updating high resolution geologic models using fluid flow, transport, and geophysical data, are emphasized throughout the book.

Complete with online software applications and examples that enable readers to gain hands-on experience, this volume is an invaluable resource for graduate-level courses, as well as for academic researchers and industry practitioners in the fields of geoscience, hydrology, and petroleum and environmental engineering.

DONALD WYMAN VASCO is a Senior Scientist at the Lawrence Berkeley National Laboratory, recognized for his contributions to the development and application of asymptotic techniques to the modeling and inversion of fluid flow and geophysical data. Dr. Vasco is the recipient of the Society of Petroleum Engineers' Cedric K. Ferguson Certificate for the best peer-reviewed paper of 1999, and has authored or co-authored over 100 peer-reviewed articles on geophysical and hydrological inverse methods and modeling techniques.

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SUBSURFACE FLUID FLOW AND IMAGING

With Applications for Hydrology, Reservoir Engineering, and Geophysics

DONALD WYMAN VASCO AND AKHIL DATTA-GUPTA

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Preface

The practice of imaging has grown tremendously in the past few decades, both in sophistication and importance. There is a strong thread of commonality in the diverse quilt of applications of imaging in medicine, engineering, and the physical sciences. In particular, the same mathematical techniques, such as the use of trajectory-based and asymptotic methods, the central topic of this book, often serve as the underpinnings of each application. However, to the uninitiated, it might seem that each discipline has adopted a distinct formulation of the imaging problem. Thus, a sense of unity is lost in traversing the various applications. In addition, the development of imaging methods may be more extensive in one particular field compared to others. For example, in applied mathematics, trajectory-based imaging methods have been extended to a wide range of situations, such as diffusive and non-linear wave propagation. These advancements may not be appreciated or even known in other areas.

The goal of this book is to bring unity to the range of trajectory-based techniques for modeling fluid flow that may serve as the basis for efficient imaging algorithms. A secondary objective is to highlight the wide array of physical phenomena to which trajectory-based imaging methods lend themselves. It is widely known that a trajectory-based method, such as ray theory, is applicable to hyperbolic equations, typified by the wave equation. Less well known is the fact that trajectory-based methods may be used to study diffusive systems, governed by a parabolic equation. Similarly, ray methods for non-linear waves have been developed in applications such as gas dynamics and plasma physics, but are relatively unknown in such fields as hydrology. The fundamental techniques are then applied to important problems in the Earth sciences. Hopefully, after finishing this book the reader will glimpse the full range of trajectory-based imaging methods.

This book describes trajectory-based imaging from its mathematical formulation, through the formation and solution of the imaging equations, to the determination of the accuracy and resolution associated with the image. Our presentation is unique in that we cover a rather complete spectrum of physical phenomena. At the same time we have tried to focus on the practical side of imaging, emphasizing methods that are efficient and robust. Obtaining an image is not the end of the story, we need some measure of the reliability of our solution. We describe methods for assessing the solution, computing the resolution and uncertainty associated with an image. Finally, as illustrations, we include a wide range of applications and emphasize their similarity.

This book is intended for those involved in imaging research. It is hoped that the cross-fertilization between disciplines will spur innovation. The book is also appropriate for students involved in the physical sciences, engineering, medical imaging, and applied mathematics. Online resources including computer softwares and example data files have been provided for the reader to acquire hands on experience in the techniques and applications discussed throughout the book.

Acknowledgments

This book is a reality because of the direct and indirect contributions of many people. We are thankful to all of them, but a few warrant special mention. The Basic Energy Sciences geophysics group at Lawrence Berkeley National Laboratory and their groundbreaking work on poroelasticity was an inspiration and an education for us. Their impact on the book is clear. Particular thanks go to Dr. James Berryman, Professor Lane Johnson, and Dr. Steve Pride, who read through and commented on various chapters over the years that it took to complete this project. Many Petroleum Engineering graduate students at Texas A & M University have contributed to this effort through their thesis and dissertations. Many of the results presented here are due to their hard work and dedication. Special thanks to Dr. Lihua Zhao for reviewing the content and helping with word to LaTex conversion. We would like thank the Petroleum Engineering Department at Texas A & M, especially Dr. Dan Hill for allowing us to use the departmental resources. Thanks to the colleagues at Texas A & M, especially Dr. Michael J. King for countless discussions and for sharing his knowledge and insight on many topics in the book.

Special thanks to the U. S. Department of Energy, Basic Energy Sciences Program and Dr. Nicholas B. Woodward for longstanding financial support that led to the development of many of the concepts and techniques discussed here. Many of the applications have also been supported by the members of the industrial consortium, Model Calibration and Efficient Reservoir Imaging (MCERI) at Texas A & M.

This book would not have been possible without the help and sacrifice of our families. Thank you Dawn, Caroline, Savannah, John, Leo, and Will, for your tolerance of the distracted weekends and evenings, and for keeping me (D. W. Vasco) grounded and focused on what is really important. Thanks to Mausumi, Alina and Antara for your unwavering support and patience (A. Datta-Gupta).