VALUE OF INFORMATION IN THE EARTH SCIENCES

Integrating Spatial Modeling and Decision Analysis

Value of information (VOI) is a concept in decision theory for analyzing the value of obtaining additional information to solve a problem. Gathering the right kind and the right amount of information is crucial for any decision-making process. Already commonly used in medicine, economics, and finance, VOI is becoming increasingly popular with Earth scientists.

This book presents a unified framework for assessing the value of potential data gathering schemes by integrating spatial modeling and decision analysis, with a focus on the Earth sciences. The authors discuss and compare the value of imperfect versus perfect information and the value of total versus partial information, where only subsets of the data are acquired. Concepts are illustrated using a suite of quantitative tools from decision analysis, such as decision trees and influence diagrams, as well as models for continuous and discrete dependent spatial variables, including Bayesian networks, Markov random fields, Gaussian processes, and multiple-point geostatistics. Numerous examples are used to illustrate the applicability of VOI to topics such as energy, geophysics, geology, mining, and environmental science. Real datasets and MATLAB codes are also provided as online supplementary material.

Unique in its scope, this book is of interest to students, researchers, and industry professionals in the Earth and environmental sciences who use applied statistics and decision analysis techniques, and particularly to those working in petroleum, mining, and environmental geoscience.

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CAMBRIDGE
UNIVERSITY PRESS

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University Printing House, Cambridge CB2 8BS, United Kingdom

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107040267

First published 2015

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication Data
Eidsvik, Jo, 1973–
Value of information in the earth sciences : integrating spatial modeling and decision analysis / Jo Eidsvik, Tapan Mukerji, and Debarun Bhattacharjya.
pages cm
Includes bibliographical references and index.
ISBN 978-1-107-04026-7 (hbk)
1. Earth sciences–Information services. 2. Geochemical prospecting. 3. Communication in science. I. Mukerji, Tapan, 1965– II. Bhattacharjya, Debarun. III. Title.
QE26.3.E35 2015
550.01'156–dc23 2015022572

ISBN 978-1-107-04026-7 Hardback

Additional resources for this publication at www.cambridge.org/eidsvik

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Preface

This book is a result of our collaboration over the past decade on addressing problems related to the value of information (VOI) in Earth sciences applications by building links between statistics, geosciences, and decision analysis. We believe that such an interdisciplinary approach will become increasingly essential for the careful stewardship of our natural resources.

Decisions related to the Earth's natural resources are often consequential, and making these decisions under uncertainty is a ubiquitous challenge. Since there is a lot at stake, it may be worthwhile for the decision maker to obtain more information before the decision is actually made – i.e., before an irrevocable allocation of resources. When faced with uncertainty, gathering the right kind and right amount of information is crucial. Today, geo-coded data are commonly purchased, processed, and interpreted to provide information about uncertain variables, such as the spatial distribution of trees in a forest, the amount of oil or gas in the subsurface, the level of groundwater in an aquifer, or the mineral content in a mine. A crucial question to answer is: how much information should one purchase, and at what price? This question is related to the well-established concept of VOI. Additional information may help to reduce the uncertainty, but if the information has no impact on the decision, then purchasing it is not economic.

A key characteristic of applying the decision theoretic notion of VOI to the Earth sciences that makes it different from other applications is the spatial aspect: spatial uncertainty, spatially distributed information, and spatial decisions. The decision theoretic formalism provides a consistent basis for relating statistical models of spatial phenomena to the decisions. This connection facilitates decision making by providing clarity of action and also fosters innovative approaches for designing spatial information-gathering schemes.

The book presents a unified framework for VOI analysis based on statistical concepts, geological and geophysical modeling, and decision analysis. Often in the Earth sciences, information is sensed remotely – for example, from geophysical surveys that provide indirect and imperfect knowledge about the spatially varying surface. How valuable is this imperfect information? We study the comparison of various kinds of practical schemes by considering the value of imperfect versus perfect information and the value of total versus partial information, where only subsets of the possible data are acquired – for example, a sparse versus a spatially dense survey.

We focus on areas of our own expertise for the benefit and interest of others with similar scientific backgrounds. Throughout the book, we will discuss and reference the work of others, but we do not aim to provide an exhaustive summary of what has been done on applying VOI to other fields, such as in medicine. Applications from the Earth sciences are highlighted, and we describe the practical use of our methods and tools via a number of illustrative examples and hands-on exercises so that readers can learn the concepts by applying them.

Even though this is a specialized book, we aim to reach a diverse group of readers. The primary intended readers include scientists, engineers, graduate students, and professionals who use applied statistics and decision theoretic models in the quantitative Earth sciences. We believe that the topics will be of interest to researchers and industry professionals in different fields of the Earth sciences: energy resources, mining, groundwater, and environmental sciences. It will also be of interest to applied statisticians and decision analysts. We hope that this book will be a practitioner's guide.

The book requires some background in basic probability and statistics and mathematical calculus, as well as an interest in Earth sciences applications. Although it is not essential, it helps to know basic multivariate analysis and decision analysis or optimization. The reader must be open to learning unfamiliar topics and be able to appreciate the added value obtained from the multidisciplinary approach. If more background knowledge is needed for a particular topic, readers can consult some of the references suggested in the bibliographic notes at the end of each chapter. The chapters define the concepts using mathematics, but without going into too much detail. Additional mathematical details about the most important models and methods used in the book are provided in the appendix. The last chapter contains exercises and larger projects including data. On the website (srb.stanford.edu/VOI), we provide more background for these examples, including data and computer code.

We hope that you find this book useful!

Acknowledgments

We would like to acknowledge the contribution of several friends, colleagues, and collaborators who have helped us in our endeavors toward the preparation and completion of this book. This includes our co-authors on various papers pertaining to value of information (VOI) in the Earth sciences: Jef Caers, Geetartha Dutta, Maren Drange-Espeland, Steinar Ellefmo, Evangelos Evangelou, Ragnar Hauge, Ketil Hokstad, Rosemary Knight, Marie Lilleborge, Gabriele Martinelli, Sara Rekstad, Javad Rezaie, Richard Sinding-Larsen, and Whitney Trainor-Guitton. We received valuable feedback on preliminary chapter drafts from Lea Deleris, Jeffrey Keisler, Gabriele Martinelli, Sameer Parakh, Deepanshu Kumar, Javad Rezaie, Ingelin Steinsland, and Ulrich Theune. We are very grateful to those who helped design and prepare creative artwork for the book: Hessam Moussavinik, Ryan Nilsen, Mamta Parakh, and Sachin Premasuthan. We are indebted to Henning Omre for laying the foundation for our NTNU–Stanford collaboration, as well as Gary Mavko and John Weyant for their encouragement on these research topics, including supporting Debarun Bhattacharjya for a few quarters during his graduate studies at Stanford University. Gary and Henning in particular planted the seeds that grew into this collaboration. Ross Shachter and Ron Howard played an important role in revealing the power of VOI. We acknowledge the long-term support from the members of the Uncertainty in Reservoir Evaluation (URE) at NTNU, the Stanford Center for Reservoir Forecasting (SCRF), and the Stanford Rock Physics and Borehole Geophysics (SRB) consortia. The Department of Energy Resources Engineering at Stanford University hosted Jo Eidsvik during his sabbatical, allowing us to finally finish the manuscript. Finally, we thank our families for their unwavering support.