SEISMIC INTERFEROMETRY

Seismic interferometry is an exciting new field in geophysics that utilizes multiple scattering events to provide unprecedented views of the Earth's subsurface structures. This is the first book to describe the theory and practice of seismic interferometry with an emphasis on applications in exploration seismology.

The book is written at a level suitable for physical scientists who have some familiarity with the principles of wave propagation, Fourier transforms, and numerical analysis. Exercises are provided at the end of each chapter, and many chapters are supplemented by online MATLAB codes (available at www.cambridge.org/schuster) that illustrate important ideas and allow readers to generate synthetic traces and invert these to determine the Earth's reflectivity structure. Later chapters reinforce these principles by deriving the rigorous mathematics of seismic interferometry.

The book includes examples that apply interferometric imaging to both synthetic data and field data from applied geophysics, but examples and chapters devoted to earthquake applications are also incorporated. Presenting many new concepts for the first time, the book is a valuable reference for academic researchers and oil industry professionals seeking to learn more about this technique. It can also be used to teach a one-semester course for advanced students in geophysics and petroleum engineering.

Gerard Thomas Schuster received his Ph.D. in Geophysics from Columbia University in 1984. He took up a faculty position at the University of Utah in 1985, where he is currently Professor of Geophysics and the founder and director of the Utah Tomography and Modeling/Migration (UTAM) consortium of oil, gas, and mining companies. He served as Chief Editor of the journal *Geophysics* from 2004 to 2005, and was a co-recipient of the 2008 Eötvös prize from the EAGE for the best paper in the journal *Geophysical Prospecting*. Professor Schuster has been invited to give short courses in seismic imaging and signal processing methods to major petroleum exploration companies throughout the world, and was the invited Society of Petroleum Engineers (SPE) Distinguished Lecturer for 1998–1999.

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GERARD SCHUSTER
University of Utah, USA

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521871242

First published 2009

Printed in the United Kingdom at the University Press, Cambridge

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

ISBN 978-0-521-87124-2 hardback

Cambridge University Press
978-0-521-87124-2 - Seismic Interferometry
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Preface

This book describes the theory and practice of seismic interferometry, with an emphasis on applications in exploration seismology. It is written at the level where it can be understood by physical scientists who have some familiarity with the principles of wave propagation, Fourier transforms, and numerical analysis. The book can be taught as a one-semester course for advanced seniors and graduate students in the physical sciences and engineering. Exercises are given at the end of each chapter, and many chapters come with MATLAB codes that illustrate important ideas.

Correlating a pair of recorded seismic traces with one another and summing the resulting correlogram for different shot records[1] is the basic processing step of seismic interferometry. This typically results in a new trace with a virtual source and/or receiver location, also known as a redatumed trace. The redatumed trace simulates a trace as if a real shot and/or receiver were at the new datum.

The redatuming procedure has been used by the exploration geophysics community since the early 1970s, except one of the traces in the correlation pair is computed by a numerical procedure such as ray tracing while the other trace is naturally recorded. Ray tracing, or more generally numerical modeling, uses an imperfect model of the Earth's velocity distribution which leads to defocusing errors in model-based redatuming. In contrast, seismic interferometry is free of such problems because it only uses recorded traces in the correlation.[2] This freedom also allows one to utilize all of the events in the trace, including higher-order multiples and coherent noise such as surface waves, leading to enhanced resolution, illumination, and the signal-to-noise ratio in the reflectivity image.

The key principles of interferometry are heuristically described in Chapter 1, and by its end the diligent reader will be using MATLAB code to generate synthetic traces, redatum these data by summed cross-correlations, and invert the redatumed

[1] The seismograms recorded for a single source are sometimes called a shot record.
[2] However, defocusing problems in interferometry arise because of the limited extent of the sources and receivers.

Cambridge University Press
978-0-521-87124-2 - Seismic Interferometry
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traces for the Earth's reflectivity structure. Later chapters reinforce these principles by deriving the rigorous mathematics of seismic interferometry. In particular, the governing equation of interferometry is known as the reciprocity equation of correlation type (Wapenaar, 2004). Many examples are presented that apply interferometric imaging to both synthetic data and field data. The terminology and examples mostly come from the applied geophysics community, but there are examples and chapters devoted to earthquake applications. The non-geophysicist will benefit by reading the brief overview of exploration seismology in Appendix 1 of the first chapter.

About 90 percent of the book deals with deterministic source interferometry where individual sources are excited with no temporal overlap in their seismic signals. This type of data is collected by applied geophysicists, and is also recorded by earthquake seismologists for strong teleseismic earthquakes. In contrast, diffuse wavefield interferometry introduced in Chapter 10 analyzes seismic wavefields with random amplitudes, phases, and directions of propagation. This topic has led to significant success for earthquake seismologists in inverting seismic surface waves recorded by passive earthquake networks. It will enjoy even more popularity as large arrays such as the USArray become more widely deployed. Diffuse wavefield interferometry in applied geophysics is undergoing vigorous scrutiny, but has not yet developed applications with widespread use. One of the dreams of exploration geophysicists is to monitor the health of oil reservoirs by passive seismic interferometry.

Finally, this book not only summarizes some of the most recent advances of seismic interferometry but also presents a partial road map for future research. It is my hope that the graduate-student reader will gain enough understanding so she or he can help complete and expand this road map.

Acknowledgments

The author wishes to thank the long-term support provided by the sponsors of the Utah Tomography and Modeling/Migration consortium. Their continued financial support through both lean and bountiful years was necessary in bringing this book to fruition. The American Chemical Society is acknowledged for their 2007–2009 grant ACS-45408-AC8 that resulted in the development of seismic source and reflectivity estimation with a natural Green's function. The National Science Foundation is also thanked for providing early seed grant money to study earthquake applications of seismic interferometry, Robert Nowack is to be thanked as a supportive co-principal investigator, and Jianming Sheng is acknowledged for his innovative work with earthquake interferometry. Jim Pechmann and Kris Pankow are thanked for their invaluable guidance in working with teleseismic data.

A crucial jumpstart in our interferometry research was the DOE grant given to us in the mid 1990s under the direction of Fred Followill and Lew Katz. They exposed the author to Katz' innovative method of 1D autocorrelogram imaging of VSP data. This was followed in 2000 with the generous invitation by Jon Claerbout to visit Stanford during four months of the author's sabbatical, which was crucial in putting together some pieces of the interferometry puzzle. Some of these pieces were given life by the expert computer implementation of Jianhua Yu, a pioneer of numerical VSP interferometry. His interferometry work during 2000–2004 yielded many VSP results that finally convinced the skeptics about its advantages over conventional VSP imaging. The early field data sets were provided by BP under the guidance of Brian Hornby. Drs. Hornby and Jianhua Yu (now at BP) pushed the practical application of VSP interferometry to new limits by applying these methods to important Gulf of Mexico data.

I also thank Sam Brown, Weiping Cao, Wei Dai, Steve Ihnen, Robert Nowack, Evert Slob, Yonghe Sun, Gerrit Toxopeus, and Dan Trentman, J. van der Neut, and Xin Wang for helping to edit portions of this manuscript. They made many valuable suggestions in both style and content that helped to improve the quality of this book. Robert Nowack and Yonghe Sun suggested many useful changes in every chapter. Dan Trentman is gratefully acknowledged for writing a Perl script that created the index in this book.

Finally, many thanks go to the following students or postdocs who generously donated their results or MATLAB codes to this book: Chaiwoot Boonyasiriwat, Weiping Cao, Shuqian Dong, Mark Fan, Sherif Hanafy, Ruiqing He, Zhiyong Jiang, Jianming Sheng, Yibo Wang, Yanwei Xue, Xiang Xiao, and Ge Zhan. Their diligent efforts have resulted in many interesting results, some of which are contained in this book.