

Seismic Interferometry: History and Present Status

Edited by

*Kees Wapenaar
Deyan Draganov
Johan O. A. Robertsson*

SEG Geophysics Reprint Series No. 26

Michael A. Pelissier, managing editor



Society of Exploration Geophysicists

The international society of applied geophysics

Tulsa, Oklahoma, U.S.A.

Table of Contents

About the Editors	xi
Chapter 1 Introduction	1
Acknowledgments	3
References	3
Suggestions for further reading	3
Chapter 2 Seismic Interferometry without Equations	9
GEOPHYSICS bright spots	10
<i>Stephen J. Hill</i> , 2006, <i>THE LEADING EDGE</i> , 25 , 1078–1081.	
Seismic interferometry — Turning noise into signal	14
<i>Andrew Curtis, Peter Gerstoft, Haruo Sato, Roel Snieder, and Kees Wapenaar</i> , 2006, <i>THE LEADING EDGE</i> , 25 , 1082–1092.	
Virtual surface seismic data from downhole passive arrays	23
<i>Gerard Schuster</i> , 2006, <i>EAGE Workshop, Passive Seismic: Exploration and Monitoring Applications</i> , A24.	
Virtual source applications to imaging and reservoir monitoring	29
<i>A. Bakulin, A. Mateeva, K. Mehta, P. Jorgensen, J. Ferrandis, I. Sinha Herhold, and J. Lopez</i> , 2007, <i>THE LEADING EDGE</i> , 26 , 732–740.	
From order to disorder to order: A philosophical view on seismic interferometry	37
<i>Kees Wapenaar and Roel Snieder</i> , 2007, 77th Annual International Meeting, SEG, Expanded Abstracts, 2683–2687.	
Chapter 3 Highlights of Seismic Interferometry until 2003	43
Synthesis of a layered medium from its acoustic transmission response	44
<i>Jon F. Claerbout</i> , 1968, <i>GEOPHYSICS</i> , 33 , 264–269.	
Levinson inversion of earthquake geometry SH-transmission seismograms in the presence of noise	50
<i>F. Scherbaum</i> , 1987, <i>Geophysical Prospecting</i> , 35 , no. 7, 787–802.	
Time reversed acoustics	66
<i>Mathias Fink</i> , 1997, <i>Physics Today</i> , 50 , 34–40.	
Acoustic daylight imaging via spectral factorization: Helioseismology and reservoir monitoring	73
<i>James Rickett and Jon Claerbout</i> , 1999, <i>THE LEADING EDGE</i> , 18 , 957–960.	

Theory of daylight/interferometric imaging: Tutorial	77
<i>Gerard T. Schuster</i> , 2001, 63rd Annual Conference and Exhibition, EAGE, Extended Abstracts, A-032.	
On the emergence of the Green's function in the correlations of a diffuse field	81
<i>Oleg I. Lobkis and Richard L. Weaver</i> , 2001, Journal of the Acoustical Society of America, 110 , no. 6, 3011–3017.	
Long-range correlations in the diffuse seismic coda	88
<i>Michel Campillo and Anne Paul</i> , 2003, Science, 299 , 547–549.	
Synthesis of an inhomogeneous medium from its acoustic transmission response	91
<i>Kees Wapenaar</i> , 2003, GEOPHYSICS, 68 , 1756–1759.	
Recovering the Green's function from field-field correlations in an open scattering medium (L)	95
<i>Arnaud Derode, Eric Larose, Mickael Tanter, Julien de Rosny, Arnaud Tourin, Michel Campillo, and Mathias Fink</i> , 2003, Journal of the Acoustical Society of America, 113 , no. 6, 2973–2976.	
Chapter 4 Green's Function Reconstruction	99
Introduction	99
Diffuse wavefields	99
Deterministic wavefields	100
Diffuse fields in ultrasonics and seismology	102
<i>Richard L. Weaver and Oleg I. Lobkis</i> , 2006, GEOPHYSICS, 71 , no. 4, Seismic Interferometry supplement, SI5–SI9.	
Extracting the Green's function from the correlation of coda waves:	
A derivation based on stationary phase	107
<i>Roel Snieder</i> , 2004, Physical Review E, 69 , 046610.	
P-waves from cross-correlation of seismic noise	115
<i>Philippe Roux, Karim G. Sabra, Peter Gerstoft, W. A. Kuperman, and Michael C. Fehler</i> , 2005, Geophysical Research Letters, 32 , L19303.	
Correlation of random wavefields: An interdisciplinary review	119
<i>Eric Larose, Ludovic Margerin, Arnaud Derode, Bart van Tiggelen, Michel Campillo, Nikolai Shapiro, Anne Paul, Laurent Stehly, and Mickael Tanter</i> , 2006, GEOPHYSICS, 71 , no. 4, Seismic Interferometry supplement, SI11–SI21.	
Green's functions extraction and surface-wave tomography from microseisms in southern California	130
<i>Peter Gerstoft, Karim G. Sabra, Philippe Roux, W. A. Kuperman, and Michael C. Fehler</i> , 2006, GEOPHYSICS, 71 , no. 4, Seismic Interferometry supplement, SI23–SI31.	
Passive image interferometry and seasonal variations of seismic velocities at Merapi Volcano, Indonesia	139
<i>C. Sens-Schönfelder and U. Wegler</i> , 2006, Geophysical Research Letters, 33 , L21302.	

Retrieval of reflections from seismic background-noise measurements.	144
<i>Deyan Draganov, Kees Wapenaar, Wim Mulder, Johannes Singer, and Arie Verdel, 2007, Geophysical Research Letters, 34, L04305.</i>	
Nonreciprocal Green's function retrieval by cross correlation.	148
<i>Kees Wapenaar, 2006, Journal of the Acoustical Society of America, 120, no. 1, EL7–EL13.</i>	
Extracting the Green's function of attenuating heterogeneous acoustic media from uncorrelated waves.	155
<i>Roel Snieder, 2007, Journal of the Acoustical Society of America, 121, no. 5, 2637–2643.</i>	
Emergence of the acoustic Green's function from thermal noise.	162
<i>Oleg A. Godin, 2007, Journal of the Acoustical Society of America, 121, no. 2, EL96–EL102.</i>	
Unified Green's function retrieval by cross-correlation: Connection with energy principles.	169
<i>Roel Snieder, Kees Wapenaar, and Ulrich Wegler, 2007, Physical Review E, 75, 036103.</i>	
Consistency of the spatial autocorrelation method with seismic interferometry and its consequence.	183
<i>Toshiaki Yokoi and Sos Margaryan, 2008, Geophysical Prospecting, 56, 435–451.</i>	
Green's function representations for seismic interferometry.	200
<i>Kees Wapenaar and Jacob Fokkema, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI33–SI46.</i>	
Interferometric modeling of wave propagation in inhomogeneous elastic media using time reversal and reciprocity.	214
<i>Dirk-Jan van Manen, Andrew Curtis, and Johan O. A. Robertsson, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI47–SI60.</i>	
Seismic interferometry: Reconstructing the earth's reflection response.	228
<i>Deyan Draganov, Kees Wapenaar, and Jan Thorbecke, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI61–SI70.</i>	
Removing free-surface multiples from teleseismic transmission and constructed reflection responses using reciprocity and the inverse scattering series.	238
<i>Chengliang Fan, Gary L. Pavlis, Arthur B. Weglein, and Bogdan G. Nita, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI71–SI78.</i>	
Unified Green's function retrieval by cross correlation.	246
<i>Kees Wapenaar, Evert Slob, and Roel Snieder, 2006, Physical Review Letters, 97, 234301.</i>	
On estimating the impulse response between receivers in a controlled ultrasonic experiment.	250
<i>K. van Wijk, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI79–SI84.</i>	
Seismic interferometry with a TBM source of transmitted and reflected waves.	256
<i>Flavio Poletto and Lorenzo Petronio, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI85–SI93.</i>	
Improved Green's functions for passive-source structural studies.	265
<i>Jean-Philippe Mercier, Michael G. Bostock, and Adam M. Baig, 2006, Geophysics, 71, no. 4, Seismic Interferometry supplement, SI95–SI102.</i>	

Transmission to reflection transformation of teleseismic wavefields	273
<i>M. Ravi Kumar and M. G. Bostock, 2006, Journal of Geophysical Research, 111, B08306.</i>	
Application of seismic interferometry to natural earthquakes	
 measured by small-scale array.	282
<i>Kentaro Torii, Toshifumi Matsuoka, Kyosuke Onishi, Kazuya Shiraishi, Takao Aizawa, Yoshiaki Yamanaka, Syunichiro Ito, Toshinori Kimura, Youichi Asano, and Tetsuya Takeda, 2007, 77th Annual International Meeting, SEG, Expanded Abstracts, 1362–1366.</i>	
Interferometric prediction and least squares subtraction of surface waves	287
<i>Shuqian Dong, Reiqing He, and Gerard T. Schuster, 2006, 76th Annual International Meeting, SEG, Expanded Abstracts, 2783–2786.</i>	
Interferometric surface-wave isolation and removal	291
<i>David F. Halliday, Andrew Curtis, Johan O. A. Robertsson, and Dirk-Jan van Manen, 2007, GEOPHYSICS, 72, no. 5, A69–A73.</i>	
On the relation between seismic interferometry and the migration resolution function	296
<i>Jan Thorbecke and Kees Wapenaar, 2007, GEOPHYSICS, 72, no. 6, T61–T66.</i>	
Electromagnetic Green’s functions retrieval by cross-correlation and	
 cross-convolution in media with losses	302
<i>Evert Slob and Kees Wapenaar, 2007, Geophysical Research Letters, 34, L05307.</i>	
Global-scale seismic interferometry: Theory and numerical examples.	307
<i>Elmer Ruigrok, Deyan Draganov, and Kees Wapenaar, 2008, Geophysical Prospecting, 56, 395–417.</i>	
Chapter 5 Redatuming	331
<i>Introduction</i> 331	
Fermat’s interferometric principle for target-oriented traveltimes tomography	333
<i>Gerard T. Schuster, 2005, GEOPHYSICS, 70, no. 4, U47–U50.</i>	
The virtual source method: Theory and case study	337
<i>Andrey Bakulin and Rodney Calvert, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI139–SI150.</i>	
On the fundamentals of the virtual source method	349
<i>Valeri Korneev and Andrey Bakulin, 2006, GEOPHYSICS, 71, no. 3, A13–A17.</i>	
A theoretical overview of model-based and correlation-based redatuming methods.	354
<i>Gerard T. Schuster and Min Zhou, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI103–SI110.</i>	
Redatuming CDP data below salt with VSP Green’s function	362
<i>Xiang Xiao and Gerard T. Schuster, 2006, 76th Annual International Meeting, SEG, Expanded Abstracts, 3511–3515.</i>	
Spurious multiples in seismic interferometry of primaries.	367
<i>Roel Snieder, Kees Wapenaar, and Ken Lerner, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI111–SI124.</i>	

Using the inverse scattering series to predict the wavefield at depth and the transmitted wavefield without an assumption about the phase of the measured reflection data or back propagation in the overburden.	381
<i>A. B. Weglein, B. G. Nita, K. A. Innanen, E. Otnes, S. A. Shaw, F. Liu, H. Zhang, A. C. Ramírez, J. Zhang, G. L. Pavlis, and C. Fan, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI125–SI137.</i>	
Equivalence of the virtual-source method and wave-field deconvolution in seismic interferometry	394
<i>Roel Snieder, Jon Sheiman, and Rodney Calvert, 2006, Physical Review E, 73, 066620.</i>	
Interferometry in dissipative media: Addressing the shallow sea problem for seabed logging applications.	403
<i>Evert Slob, Kees Wapenaar, and Roel Snieder, 2007, 77th Annual International Meeting, SEG, Expanded Abstracts, 559–563.</i>	
Virtual shear source makes shear waves with air guns	408
<i>Andrey Bakulin, Albena Mateeva, Rodney Calvert, Patsy Jorgensen, and Jorge Lopez, 2007, GEOPHYSICS, 72, no. 2, A7–A11.</i>	
Improving the virtual source method by wavefield separation.	413
<i>Kurang Mehta, Andrey Bakulin, Jonathan Sheiman, Rodney Calvert, and Roel Snieder, 2007, GEOPHYSICS, 72, no. 4, V79–V86.</i>	
Cross-well seismic survey without borehole source	421
<i>S. Minato, K. Onishi, T. Matsuoka, Y. Okajima, J. Tsuchiyama, D. Nobuoka, H. Azuma, and T. Iwamoto, 2007, 77th Annual International Meeting, SEG, Expanded Abstracts, 1357–1361.</i>	
Acquisition geometry requirements for generating virtual-source data	426
<i>Kurang Mehta, Roel Snieder, Rodney Calvert, and Jonathan Sheiman, 2008, THE LEADING EDGE, 27, 620–629.</i>	
Interferometry by deconvolution: Part 1 — Theory for acoustic waves and numerical examples	434
<i>Ivan Vasconcelos and Roel Snieder, 2008, GEOPHYSICS, 73, no. 3, S115–S128.</i>	
Chapter 6 Imaging	449
Introduction	449
Diffuse wavefields	450
Deterministic wavefields	451
References	452
Time-reversal acoustics in complex environments	454
<i>Mathias Fink, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI151–SI164.</i>	
Coherent interferometric imaging in clutter.	468
<i>Liliana Borcea, George Papanicolaou, and Chrysoula Tsogka, 2006, GEOPHYSICS, 71, no. 4, Seismic Interferometry supplement, SI165–SI175.</i>	

Imaging passive seismic data	479
<i>Brad Artman</i> , 2006, <i>GEOPHYSICS</i> , 71 , no. 4, Seismic Interferometry supplement, SI177–SI187.	
Passive seismic reflectivity imaging with ocean-bottom cable data	490
<i>Detlef Hohl and Albená Mateeva</i> , 2006, 76th Annual International Meeting, SEG, Expanded Abstracts, 1560–1564.	
Using symmetry breaking in time reversal mirror for attenuation determination	495
<i>A. Gosselet and S. C. Singh</i> , 2007, 77th Annual International Meeting, SEG, Expanded Abstracts, 1639–1643.	
Interferometric imaging condition for wave-equation migration	500
<i>Paul Sava and Oleg Poliannikov</i> , 2008, <i>GEOPHYSICS</i> , 73 , no. 2, S47–S61.	
Cross-correlation of random fields: Mathematical approach and applications	515
<i>P. Gouédard, L. Stehly, F. Brenguier, M. Campillo, Y. Colin de Verdière, E. Larose, L. Margerin, P. Roux, F. J. Sánchez-Sesma, N. M. Shapiro, and R. L. Weaver</i> , 2008, <i>Geophysical Prospecting</i> , 56 , 375–393.	
Interferometric/daylight seismic imaging	534
<i>G. T. Schuster, J. Yu, J. Sheng, and J. Rickett</i> , 2004, <i>Geophysical Journal International</i> , 157 , 838–852.	
Crosscorrelogram migration of inverse vertical seismic profile data	549
<i>Jianhua Yu and Gerard T. Schuster</i> , 2006, <i>GEOPHYSICS</i> , 71 , no. 1, S1–S11.	
Comparison between interferometric migration and reduced-time migration of common-depth-point data	560
<i>Min Zhou, Zhiyong Jiang, Jianhua Yu, and Gerard T. Schuster</i> , 2006, <i>GEOPHYSICS</i> , 71 , no. 4, Seismic Interferometry supplement, SI189–SI196.	
Imaging of multiple reflections	568
<i>A. J. Berkhout and D. J. Verschuur</i> , 2006, <i>GEOPHYSICS</i> , 71 , no. 4, Seismic Interferometry supplement, SI209–SI220.	
Migration of interbed multiple reflections	580
<i>Zhiyong Jiang</i> , 2006, 76th Annual International Meeting, SEG, Expanded Abstracts, 3501–3505.	
Teleseismic shot-profile migration	585
<i>J. Shragge, B. Artman, and C. Wilson</i> , 2006, <i>GEOPHYSICS</i> , 71 , no. 4, Seismic Interferometry supplement, SI221–SI229.	
Salt-flank delineation by interferometric imaging of transmitted P- to S-waves	594
<i>Xiang Xiao, Min Zhou, and Gerard T. Schuster</i> , 2006, <i>GEOPHYSICS</i> , 71 , no. 4, Seismic Interferometry supplement, SI197–SI207.	
A novel application of time-reversed acoustics: Salt-dome flank imaging using walkaway VSP surveys	605
<i>Mark E. Willis, Rongrong Lu, Xander Campman, M. Nafi Toksöz, Yang Zhang, and Maarten V. de Hoop</i> , 2006, <i>GEOPHYSICS</i> , 71 , no. 2, A7–A11.	

Interferometric imaging of a salt flank using walkaway VSP data	610
<i>Brian E. Hornby and Jianhua Yu, 2007, THE LEADING EDGE, 26, 760–763.</i>	
Target-oriented interferometric tomography for GPR data	614
<i>Sherif M. Hanafy and Gerard T. Schuster, 2007, GEOPHYSICS, 72, no. 3, J1–J6.</i>	
3D wave-equation interferometric migration of VSP free-surface multiples	620
<i>Ruiqing He, Brian Hornby, and Gerard Schuster, 2007, GEOPHYSICS, 72, no. 5, S195–S203.</i>	