Wave Inversion Technology Consortium

Campinas Karlsruhe Hamburg

WIT

Wave Inversion Technology
established 1996 in Karlsruhe, Germany

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University of Hamburg

Hamburg, Germany

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

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Preface

Another year has gone by, which we celebrate with a brand new annual report. This seventeenth volume since the foundation of WIT represents the whole bandwidth of WIT research. You will find twenty-three papers on a broad variety of topics ranging from imaging over modelling to full waveform inversion and others. The report's range in topics benefits from the special construction of the WIT project comprising three individual teams with different focus and approaches to provide leading edge research in seismic exploration.

This report presents the scientific results of the WIT teams in 2013. There is, however, more to report on the fruits of our research.

We would like to share a few of the 'highlights' from 2013 with you, beginning with awards presented to WIT researchers. Lisa Groos was awarded for the best oral presentation at the annual meeting of the Deutsche Geophysikalische Gesellschaft (DGG) for her work entitled '2D full waveform inversion of a shallow seismic field dataset: Preprocessing and first inversion results'.

Furthermore, the Society of Exploration Geophysicists (SEG) bestowed the prestigious Maurice Ewing Award on former WIT director Peter Hubral. This award was established for the first time in 1978 and is the highest honour given by SEG to a person who is deserving of special recognition through having made major contributions to the advancement of the science and profession of exploration geophysics. Peter is a founding member of WIT, and we congratulate him from the bottom of our hearts for the appreciation that comes with this award.

Moreover, GEOPHYSICS published a special section on seismic anisotropy in 2013 which was co-edited by WIT researchers Dirk Gajewski and Claudia Vanelle.

One of the reasons for the success of WIT research lies in our pool of promising young scientists. We congratulate Drs. Rodrigo Bloot, Lisa Groos, Anna Przebindowska, Ines Veile, and Oksana Zhebel for successfully defending their Ph.D. in 2013. You will find some of their theses on the accompanying WIT-CD, together with selected Master theses. We are very pleased that several junior researchers who completed their M.Sc. in 2013 have decided to continue working with us in a Ph.D. programme. To promote these young scientists is also thanks to your generous and continuous support.

We would like to draw your attention to a workshop on multiparameter processing that will be held during the 2014 annual EAGE meeting in Amsterdam. WIT scientists, including J. Pruessmann (TEEC) and Evgeny Landa (OPERA) will act as conveners. The main objectives of the workshop focus on determining the position of multiparameter methods in contemporary processing and imaging workflows, and investigating their future potential.

Last, not least, we acknowledge your support. As public funding programmes for research on specific topics are usually limited to a few years of support, our long term research would not have been possible without your continuing sponsorship. Some of you have been with us for many years and witnessed developments that could not have been achieved within two or three years only. Not only do you provide us with a solid foundation for our research, but also the means to offer our fledgling scientists the best possible education. For all of this, we express our appreciation and gratitude, on behalf of all the WIT teams.

Hamburg, 2014/17/02, Dirk Gajewski and Claudia Vanelle

Summary: WIT report 2013

IMAGING

Adetokunbo et al. investigate the influence of the spread length on the determination of stacking attributes with the CRS and i-CRS operator.

Ahmed et al. present an application of the 3D-CRS workflow to hard rock data. The considered data are low fold and the emphasize of the study is on coherence since it provides better images than the stack.

Borin et al. provide an overview of the 3D ZO CRS Stack software, including its parallel execution model, and an analysis of the performance of the software when executing large data sets. The authors show that the current implementation of the `makeGeometry` procedure hinders the processing of large (1TB) data sets and present a solution for the problem.

Coimbra et al. extend their diffraction-based migration-velocity-analysis method to the prestack domain. The algorithm uses the focusing of remigration velocity rays from uncollapsed migrated diffraction curves to iteratively update the velocity model. Since the velocity rays are constructed from a ray-tracing like approach, the method has a very low computational cost between migrations. Synthetic data examples demonstrate the method's feasibility.

Barrera et al. combine modeling with interferometry and correlate the modeled direct wavefield with seismic surface data to relocate the acquisition system to any datum in the subsurface to which the propagation of direct waves can be modeled with sufficient accuracy. They demonstrate theoretically and numerically that reflections from deeper interfaces are repositioned with satisfactory accuracy.

Coimbra et al. present a prestack time-migration tool for local improvement of the seismic migration-velocity model, based on time-remigration trajectories. Kinematic parameters from local-slope information of seismic reflection events are used to locally correct the velocity model. The main advantage of this technique is that it allows to carry out a residual moveout correction for all offsets of a common image gather (CIG), taking into account the reflection-point displacement in the midpoint direction. Tests on synthetic and SMAART-Sigsbee2B data demonstrated the feasibility of the method.

Gelius and Tygel revisit seismic imaging employing integral-equation type of migration. To further improve the resolution of the reconstruction of both reflections and diffractions, they propose to employ ideas taken from Fresnel-aperture migration which uses low-frequency stationarity to select that part of data that coherently contribute to the final image. The approach offers an efficient way to window the coherent reflection energy which if being aligned, which, together with a window-steered MUSIC approach, has the potential of giving high-resolution seismic images.

Gelius and Tygel revisit ray-based approaches to stacking and time-migration of seismic data, and investigate the role of the smooth-velocity condition normally attached to such techniques. It is shown that the smooth velocity field plays the role of a replacement medium in such a way that the one-way analogues of the stacking and time-migration operators can be approximated, in a paraxial sense, by its impulse responses. It is shown how stacking and time-migration velocities relate to useful properties along the central or mapping ray of the impulse responses.

Koushesh et al. evaluate the power of CRS and i-CRS methods in interpolating and enhancing of signal to noise ratio in pre-stack data.

Novais et al. investigate the theoretical expression of the Li correction in order to approximate the involved Fourier transforms by means of the method of stationary phase. They find a simple phase-correction factor in space, using the direction of wave propagation as the dominant direction. Numerical experiments with the exact propagation angle show that the so-achieved correction has acceptable quality with considerable reduction in computational cost.

Santos et al. discuss two recent time MVA methods, being common-image-gather image-wave propagation and double multi-stack migration, and compare their potential for the construction of initial models for more sophisticated MVA techniques. At the example of the Marmousoft dataset, they show that both methods can be used in a fully automated procedure to produce a velocity model and a time-migrated image without a-priori information at comparable cost.

Schleicher et al. study various ideas of using weights in the imaging condition of blended-shot migration, in order to reduce crosstalk. They combine the ideas of random phase and/or amplitude encoding and random alteration of the sign with additional multiplication with powers of the imaginary unit. The results indicate that with a combination of these weights, the crosstalk can be reduced by a factor of 4. Moreover, they compare random shot grouping with one based on Costas arrays. The objective is to avoid the occurrence of patterns in the distribution, in this way reducing coherent crosstalk energy. Finally, they show that the crosstalk noise can be reduced after migration by image processing.

Schwarz et al. provide a generalized view on current multi-parameter stacking techniques. They indicate that all higher-order traveltime approximations, despite being parameterized with the same set of attributes, are based on the straight ray assumption and can be devided into two main subcategories, which behave fundamentally different when heterogeneity is present. The authors suggest a simple recipe for the transformation from one category to the other and argue that both types of operators have distinct advantages, either accounting well for heterogeneity or leading to an efficient implementation.

MODELING

Camargo and Santos analyse a FD scheme for the acoustic wave equation, with an adaptive spatial operator which reduces the computational cost but not the accuracy. The idea is to use long operators in low velocity regions and short operators in high velocity ones.

Gelius and Tygel discuss the validity of the first Born approximation that is used in the inversion of marine Controlled Source Electromagnetic (mCSEM) data. An extended Born approximation is advocated for which provides significantly more accurate results with a modest increase of computational effort.

Voegele et al. point up the well-known stability issues of a pseudo-acoustic wave equation on numerous 2D TTI macro-models. By varying the amount of shear-wave velocity along the symmetry axis they get a better insight in the activation of non-physical solutions for the wave equation. In this way, a common thread between the parameters for anisotropy and the occurring instabilities is derived.

FULL WAVEFORM INVERSION

Butzer et al. shows the application of a diagonal Hessian approximation for preconditioning in 3D elastic full waveform inversion.

Heider et al. show a synthetic example for inverting a random distributed velocity model and prior steps to invert for the field data.

Macedo et al. apply scattering theory to the time-lapse problem, considering the time-lapse change as a perturbation of the singular part of the model. They make use of the time-lapse differential-waveform inversion framework, with the linearized scattering-based decomposition of the sensitivity kernel. Their numerical examples demonstrate that the inclusion of the singular part into the model used for back-propagation helps to improve the perturbation estimates from FWI by taking advantage of the additional subsurface illumination provided by multiple-scattering phenomena.

Schäfer et al. present two field datasets which they acquired to test their 2D full waveform inversion (FWI) approach. They discuss the main preprocessing steps applied to the field data as well as first FWI results.

Thiel et al. investigate the potential of Full Waveform Inversions (FWI) applied on the subsalt imaging problem. Synthetic acoustic and elastic FWI tests were performed for a marine 2D profile. The Flooding Technique is applied and further developed.

OTHER TOPICS

Pereira and Biloti present an stationary phase analysis for the seismic interferometrical interpolation of traces in the presence of dipping reflectors.

Vanelle provides an algorithm for the generation of analytical traveltimes for waves reflected by a spherical interface.

The Wave Inversion Technology (WIT) Consortium

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The Wave Inversion Technology Consortium (WIT) was established in 1996 and is organized by the Institute of Geophysics of the University of Hamburg. It consists of three integrated working groups, one at the University of Hamburg and two at other universities, being the Mathematical Geophysics Group at Campinas University (UNICAMP), Brazil, and the Geophysical Institute of the Karlsruhe University. In 2003, members of the Geophysical Department at the Federal University of Pará, Belém, Brazil, have joined WIT as an affiliate working group. In 2007, NORSAR joined WIT as research affiliate. In 2010, Fraunhofer ITWM joined WIT as research affiliate.

The WIT Consortium offers the following services to its sponsors:

a.) research as described below;

b.) deliverables;

c.) technology transfer and training.

The ultimate goal of the WIT Consortium is a most accurate and efficient target-oriented seismic modelling, imaging, and inversion using elastic and acoustic methods. Within this scientific context it is our aim to educate the next generations of exploration geophysicists.

Exploration and reservoir seismics aims at the delineation of geological structures that constrain and confine reservoirs. It involves true-amplitude imaging and the extrapolation of the coarse structural features of logs into space. The goals on seismic resolution are constantly increasing which requires a complementary use of kinematic and wave equation based techniques in the processing work flow. At WIT we use a cascaded system of kinematic and full wave form model building and imaging techniques. Since our data and inversions are never perfect it is the challenge to find those techniques which produce the best images for erroneous velocities and faulty wave forms.

RESEARCH TOPICS

The WIT consortium has the following main research directions, which aim at characterizing structural and stratigraphic subsurface properties. Some of the topics are studied by more than one team, applying different approaches. The WIT research is divided into five subgroups:

Processing and Imaging

The Common Reflection Surface (CRS) concept plays a key role in the WIT research on processing and imaging. The WIT hyperbolic CRS and non-hyperbolic i-CRS stacking operators are based on this concept and represent the backbone of many research topics.

- global (ZO CRS) vs. local (CO CRS) approximations
- estimation of CO CRS attributes from ZO attributes
- 3-D i-CRS operator
- wavefield decomposition using stacking attributes (multiples, reflections, diffractions)
- utilizing super resolution
- pre-stack diffraction/reflection separation
- 5-D CRS and i-CRS interpolation and pre-stack data enhancement
- improved coherence measures (MUSIC, cross-correlation, analytical trace, etc.)
- optimization of multi-dimensional coherence analysis
- data driven isotropic and anisotropic time migration
- wavefield decomposition and filtering in the CSP domain
- inverse CSP mapping
- CRS and diffraction processing of 3-D hard rock data
- angle domain migration
- beam migration
- image wave re-migration
- migrated-domain CRS methods

Model Building

Most of our model building approaches also exploit the CRS concept, which may be applied in the data or time migrated domain.

- diffraction focusing velocity analysis
- passive seismic data velocity model update
- CRS based time to depth conversion
- tomographic inversion of stacking attributes

Full Waveform Inversion

Research on Full Waveform Inversion (FWI) is moving toward applications to marine reflection seismic data and near surface seismic data (surface waves) and three-component Vibroseis data acquired in crystalline rocks.

- development of robust preprocessing of seismic data for FWI
- multi-parameter FWI
- source wavelet inversion
- accurate methods for geometrical spreading correction
- implementation of 3-D acoustic/elastic/viscoelastic FWI on HPC machines
- FWI in viscoelastic media
- optimization of Finite-Difference forward solvers used in FWI with respect to MPI communication, higher order time integration, variable spatial discretization and smooth free surface topography
- application of pseudo spectral methods in FWI

Modeling and RTM

In modeling and RTM we use FD, FE, and pseudo spectral approaches. Optimizations of the computational effort is highest on the agenda.

- 2-D and 3-D RTM for VTI and TTI media (spectral methods)
- 2-D and 3-D acoustic and elastic RTM (FD methods)
- finite element (FE) elastic wavefield modeling
- computational optimizations of FD and spectral method approaches for acoustic, elastic, and anisotropic media, including benchmarking
- improved one-way wave equation
- reflection impedance description of reflection coefficients
- tuning effects in AVO and AVA

Passive Seismics

Passive seismic signals as a diffraction event provide the link to reflection seismics. Located diffractions or micro-earthquakes provide natural Green's functions for reflection imaging.

- optimization of model-domain stacking and correlation based localization approaches
- high resolution full waveform relative event localization
- microtremor localization
- interferometric re-localization
- development of fast time-domain localization technique
- localization uncertainties (apertures, velocities, bandwidth, acquisition footprint)
- real time processing methodology

WIT STEERING COMMITTEES

Internal Steering Committee

Name	WIT team
Thomas Bohlen	Karlsruhe
Norman Ettrich	ITWM
Dirk Gajewski	Hamburg
Tina Kaschwich	NORSAR
Jörg Schleicher	Campinas
Martin Tygel	Campinas
Claudia Vanelle	Hamburg

External Steering Committee

Name	Sponsor
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Heron Antônio Schots	Centro Potiguar de Geocîencias
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Carlo Tomas	Eni
Paul Krajewski	Gaz de France SUEZ
Dan Grygier	Landmark Graphics Corporation
Jan Erik Lie	Lundin
Rune Øverås, Jon Sandvik	PSS-Geo
Henning Trappe	TEEC

COMPUTING FACILITIES

The Hamburg group has access to a 264 nodes (16 dual core CPUs, 8448 cores in total) IBM p575 "Power6" cluster at the German Computer Center for Climate Research (Deutsches Klimarechenzentrum, DKRZ) for numerically intensive calculations. It is equipped with 20 TeraByte of memory and its performance per core is 18.8 GigaFlops. There is also access to an IBM Linux cluster (Intel XEON). A SUN Fire X4600 (8 dual core Opteron, 32 GB) is exclusively available for the group's computing demands. Additional computer facilities consist of several Linux workstations and Linux PCs. Furthermore, the group has exclusive access to a Maxeler MaxWorkstation with a 24 GB memory MAX3 acceleration card which is FPGA based.

The research activities of the Campinas Group are carried out in the Computational Geophysics Laboratory. The Lab has 15 Linux PC workstations connected by a dedicated jhigh-speed network, suitable for parallel processing. Educational grants provide seismic packages from leading companies such as Landmark and Paradigm. Besides State Government funds, substantial support both for equipment and also scholarships are provided by the Brazilian Oil Company Petrobras. An extension of the Lab with substantial increase of computer power and space in the new facilities of the Center of Petroleum Studies went fully operational in 2012. The new Lab extension counts on another 30 Linux PC workstations that rely on resources shared by a high-performance server and provide access to a 3Tflops cluster with 2TB RAM. The LGC also has remote access to the computing facilities of the Petrobras Research Center in Rio de Janeiro.

The local facilities of the WIT group in Karlsruhe mainly consist in about 30 clustered quad-core Linux workstations. For large-scale computational tasks, a Hewlett-Packard XC3000 (HC3) Linux cluster and is available on campus. It hosts about 300 nodes with two quad cores each. The total nominal peak performance is 27 Teraflops, the total main memory 10 Terabyte. About 300 Terabyte disk space are available via a Lustre file system and an InfiniBand interconnect. Sharing the same file system, the WIT group in Karlsruhe co-funded and has exclusive access to the SCC Institutscluster 2 (IC2) which is a distributed memory parallel computer with 400 16-way compute nodes where each node has two Intel Xeon Octa-Core sockets with Sandy Bridge architecture, 2.6 GHz frequency and 64 GB local memory. The total nominal peak performance is 132 Teraflops, the total main memory 28.3 Terabyte. In addition, the WIT group in Karlsruhe has access to the computing facilities of the state-owned bwGRiD consisting of a total of 101 IBM blades centers distributed over seven universities in Baden-Württemberg. Furthermore, successful project proposals at the Jülich Supercomputing Centre (JSC) and the High Performance Computing Center Stuttgart (HLRS) has granted access and a large volume of computing hours for the Juropa Clustercomputer and the Cray Hermit Supercomputer. The Juropa super computer consists of 8640 cores total, 52 Terabyte main memory with a peak performance of 101 TeraïňĆops, while the Hermit cluster computer consists of 3552 cores total, about 150 Terabyte main memory and with a peak performance of 1.045 Petaflops. Both super computers will be used for large scale forward simulation and full waveform tomographies.

The main computing facility at the Geophysics Graduation Program in Belém is the Seismic Processing Lab (ProSis) . The hardware resources include: several networked Linux-PCs and for large-scale applications, a cluster of PCs with 15 dual-processor nodes with Tesla GPGPU cards in 8 nodes. The proprietary software packages available for seismic applications are ProMAX and MATLAB.

Fraunhofer ITWM builds up new compute clusters early 2014. The largest machine consists of 192 dual Intel Xeon E5-2670 ("Sandy Bridge") (i.e. 16 CPU cores per node) with 64 GB RAMeach, 300 GB HDD, 2x Gigabit Ethernet and FDR Infiniband interconnect. In total, 3072 CPU cores, 12 TB main memory, and 57 TB disk space. Estimated peak performance is 56 TFlops. In addition, 4 quad Intel Xeon E5-4650L ("Sandy Bridge") (i.e. 32 CPU cores per node) with 256 GB RAM, 2x 500 GB HDD will be available. The storage system consists of 12 storage servers, connected via FDR Infiniband an 10 Gigabit Ethernet with a total capacity of 200 TB via the Fraunhofer file system. In addition, the HPC department of ITWM runs a cluster with 92 compute nodes, among them 60 Intel Xeon E5-2680 IvyBridge nodes.

Disk capacity will be 270 TBytes.

WIT research personnel

Ivan Abakumov received his MSc from St. Petersburg University in 2013. He is now a PhD student in the University of Hamburg. His research interests are time imaging, converted waves, time-lapse seismic, full waveform inversion, geophysical data processing and computer programming. Ivan is a student member of EAGE, SGE and SPE.

Peter Adetokunbo received a B.Tech. in Applied Geophysics from the Federal University of Technology, Akure, Nigeria in 2007 and is currently a M.Sc. student in Geophysics at Earth Science Department, King Fahd University of Petroleum and Minerals, Saudi Arabia. His research interests focus on frequency dependent seismic attenuation, seismic imaging and interpretation. He is a member of SEG, SPE and IAH.

Niklas Ahlrichs is a B.Sc. student in geophysics at the University of Hamburg since 2011. His research interests focus on seismic velocity analysis.

Khawar Ashfaq Ahmed received a B.Sc. from the University of the Punjab in Lahore, Pakistan, in 2005. He received a M.Sc. in Geophysics in 2007 and a M.Phil. in Geophysics in 2009, both from the Quaid-i-Azam University in Islamabad, Pakistan, where he also worked for three years as teaching and research associate in the Department of Earth Sciences. Since 2010, he is enrolled at the University of Hamburg as a Ph.D. student in Geophysics. His recent work is 3D seismic processing with hybrid approach and diffraction mapping. His current research work is on seismic imaging in 3D Schneeberg data(crystalline environment)

Denis Anikiev received his MSc in geophysics in 2011 from Saint Petersburg State University, Russia, with a thesis "Methods of dynamic inverse problem for horizontally homogeneous media". He participated in an exchange program with Hamburg University in 2006-2009 during his work on the BSc thesis "Localization of Seismic Events by Diffraction Stacking". Since 2011 he is a Ph.D. student at Earth Physics Department in Saint Petersburg State University. The preliminary title of his Ph.D. thesis is ‘Reverse-time migration in isotropic elastic media’. His present research interests include elastic reverse-time migration, full waveform inversion, localization of seismic events, localization of microtremors, dynamic inverse problems for acoustic layered media. He is a student member of SEG, EAGE, SPE.

Parsa Bakhtiari Rad received a B.Sc. in Mine Exploration Engineering from the Islamic Azad University, Iran, in 2005 and received a M.Sc. in Exploration Seismology in 2008 from the same university with a thesis title "Application of Karhunen-Loeve Filter in Multiple Attenuation Camparison with Radon Transform on Seismic Reflection Data". He also worked for almost three years as a Data Analyst in 2D/3D seismic data processing center of OEOC-CGG companies in Tehran and as a geophysicist in data acquisition fields for geophysical section of National Iranian Oil Company(NIOC) as well. In 2012, he enrolled at the University of Hamburg as a Ph.D. student in Geophysics. His main research interest is processing and imaging of seismic diffractions.

Alexander Bauer received a B.Sc. in Geophysics from Hamburg University in 2012 and is currently M.Sc. student in the Hamburg WIT group. His research interests focus on multiparameter stacking and converted waves.

Mehrnoosh Behzadi has received her B.Sc. in physics (2004) and M.Sc. in seismology (2009) from Islamic Azad University of Tehran, Iran. Since 2011, she is a Ph.D. student in the Hamburg WIT group. Her research interests include passive seismics, site effects, and microseismicity. She is a member of EAGE.

Ricardo Biloti received his B.Sc.(1995), M.Sc. (1998) as well as Ph.D. (2001) in Applied Mathematics from the State University of Campinas (UNICAMP), Brazil. He worked at Federal University of Paraná (UFPR), Brazil, as an Adjoint Professor, at the Department of Mathematics, from May 2002 to September 2005, when he joined Unicamp as an Assistant Professor. He has been a collaborator of the Campinas Group since his Ph.D. His research areas are multiparametric imaging methods, like CRS for instance. He has been working on estimating kinematic traveltime attributes and on inverting them to construct velocity models. He is also interested in Numerical Analysis, Numerical Linear Algebra, and Fractals. He is a member of SBMAC (Brazilian Society of Applied Mathematics), SIAM and SEG.

Martina Bobsin received her B.Sc. in geophysics at the University of Hamburg in 2012 and is now an M.Sc. student in the Hamburg WIT group. Her research interests focus on multiparameter stacking operators and time migration.

Thomas Bohlen received a Diploma of Geophysics (1994) and a Ph.D. (1998) from the University of Kiel, Germany. From 2006 to 2009 he has been Professor of Geophysics at the Institute of Geophysics at the Technical University Freiberg where he has been the head of the seismics and seismology working groups. Since 2009, he is Professor of Geophysics at the Geophysical Institute of the Karlsruhe Institute of Technology. He is the head of the applied geophysics group. His research interests and experience include: seismic modelling, full waveform inversion, surface wave inversion and tomography, reflection seismic imaging. He is a member of SEG, EAGE, AGU, ASA, and DGG (member of the executive board).

Alexandre William Camargo received his BS (2011) in Applied Mathematics from the State University of Campinas (UNICAMP), Brazil. He is currently about to finish the Master Science in Applied Mathematics in the same university. His professional interests include seismic modeling and numerical methods for differential equations. He is member of SEG (Society of Exploration Geophysicists).

Pedro Chira Oliva, received his diploma in Geological Engineering (UNI-Peru/1996). He received his MSc., in 1997 and PhD., in 2003, both in Geophysics, from Federal University of Pará (UFPA/Brazil). He took part of the scientific research project "3D Zero-Offset Common-Reflection-Surface (CRS) stacking" (2000-2002) sponsored by Oil Company ENI (AGIP Division - Italy) and the University of Karlsruhe (Germany). Currently he is full Professor at the Institute of Coastal Studies (IECOS) of UFPA. His research interests include seismic stacking and seismic modeling. He is member of GOCAD consortium (France) and SBGf.

Tiago A. Coimbra received a B.Sc. (2007) in Mathematics from Federal University of Espirito Santo (UFES) and an M.Sc. (2010) in Applied Mathematics from University of Campinas (UNICAMP), Brazil. Since 2010 he has been a Ph.D. student in Applied Mathematics at UNICAMP. His research interests include seismic modeling, particularly ray theory, velocity analysis, offset continuation, and image-wave theory. He is a member of SEG and SBGf.

Jessé Carvalho Costa received his diploma in Physics in 1983 from the Physics Department, Federal University of Pará (UFPA) and a Doctor degree in Geophysics in 1993 from the Geophysics Department at the same University. He was a Summer Student at Schlumberger Cambridge Research in 1991 and 1992. He spent 1994 and 1995 as a post-doc in the Stanford Tomography Project at Stanford University. He held a faculty position the Physics Department at UFPA from 1989 to 2003. Currently he is Associate Professor in the Geophysics Department, UFPA. His fields of interest include seismic anisotropy, traveltime tomography and seismic modeling.

João Carlos Ribeiro Cruz received a BSc (1986) in geology, a MSc (1989), and a PhD (1994) in geophysics from the Federal University of Pará (UFPA), Brazil. From 1991 to 1993 he was with the reflection seismic research group of the University of Karlsruhe, Germany, while developing his PhD thesis. Since 1996 he has been full professor at the geophysical department of the UFPA. His current research interests include velocity estimation, seismic imaging, and application of inverse theory to seismic problems.

Jesper Sören Dramsch participated in the junior studies programme at the University of Hamburg in 2006. He continued his studies in Geophysics at the same university and finished his BSc thesis in 2010. Recently he is participating in the M.Sc. programme in Geophysics at the University of Hamburg. He is currently working on pre-stack data enhancement for improving sub-salt illumination..

Simone Dunkl received her diploma in geophysics at the Karlsruhe Institute of Technology (KIT) in 2010. Afterwards she started her PhD in Karlsruhe, working on 3D elastic full waveform inversion.

Norman Ettrich received his diploma in geophysics in 1993 from the Technical University of Clausthal-Zellerfeld, and a Ph.D. in geophysics (1997) from the University of Hamburg. In 1998-2002, he worked at the research center of Statoil, Trondheim. In 2002, he joined the Fraunhofer Institut für Techno- und Wirtschaftsmathematik in Kaiserslautern, Germany. Since 2005, he has been contributing to building up research activities in the fields of seismic migration, processing and visualisation. His key interests are seismic migration, seismic processing, ray tracing, and anisotropy. He is a member of EAGE and SEG.

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