FULL SEISMIC WAVEFORM MODELLING AND INVERSION

by

ANDREAS FICHTNER

Preface

Our planet is permanently vibrating, excited by oceans, atmosphere, earthquakes, or man-made sources. Luckily, Earth's physical properties are such that these vibrations – elastic waves to be more specific – often propagate to large distances carrying information on the medium they encounter along the way. The problem of making an educated guess at the subsurface structure from observations of ground motions is as old as instrumental seismology itself (so not that old, maybe a century or so). Let us call the problem *seismic tomography* akin to CT scanning in medicine, a field seismologists have always envied. Because of limitations in illuminating the Earth with sufficient coverage we have never obtained the sharp and detailed internal structures so familiar from medical imaging.

Up to now we have mostly cut corners in the way we model and fit our seismic data. We typically reduce long, wiggly seismograms to a few bytes of information (e.g., travel times, phase velocities, etc.) and try to explain these data with approximate theories. This has been for a good reason. Our computers were simply not fast and big enough to allow the calculation of complete wave fields through three-dimensional Earth structures. Frequently the data just don't warrant the use of sophisticated physics.

The situation regarding computational power in connection with three-dimensional wave propagation has dramatically changed in the past few years. Even on a global scale the calculation of wave fields across the complete observed frequency range is in sight. On smaller scales (continents, basins, volcanoes, reservoirs) we are already witnessing the emergence of three-dimensional wave propagation as *the* tool for data modelling, inversion, and parameter studies.

This was Albert Tarantola's (and others') dream 25 years ago: just simulate the physics correctly and let the data (i.e., the misfit to a theoretical seismogram) decide whether the Earth model is good or not. In his world (the probabilistic approach) this should be done using a Monte Carlo type approach: calculate zillions of models and use all the results to estimate parameters and uncertainties. Unfortunately, we are not there yet. We still need to resort to linearisations around (hopefully good) starting models and employ adjoint-type techniques to update our Earth models. Fortunately, in many situations, good starting models can be found, making iterative waveform inversion the preferred tool to improve our Earth models using most or all of the observed data.

The book in your hands is the first to provide a broad overview on how to solve the forward problem to calculate accurate seismograms in 3-D Earth models, to compare theory with observations, and to iteratively update Earth models until a satisfactory fit to observations is achieved. Many questions remain, in particular in connection with properly assessing uncertainties. Yet, the tools described here will be essential in the coming years to move forward in reconstructing the structure of Earth's interior on all scales. In that sense they will have a strong impact on many related fields in Earth sciences such as geodynamics, earthquake physics, exploration geophysics, tectonics, volcanology, and others. The book should be essential reading for everyone interested in getting the best out of seismic observations in terms of Earth's physical properties.

Heiner Igel, Munich, October 2010