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Modeling of Physical Systems

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ABSTRACT

Modeling, as a complementary counterpart of Inverse Theory, is important since it can give insight and relate understanding of physical processes without the attempt to invert measured data. Accurate modeling is a necessary step in Inversion Theory for the efficient convergence to the solution of the problem. Full wave form seismic modeling of real-world sized models with realistic complexities in three dimensions is still a challenging problem. I give a guide to practical applications of numerical modeling theory to real-world sized models. By large, I mean physical models ranging over two or more dimensions. The allowance of arbitrary model heterogeneity leaves hardly another choice than finite difference modeling techniques. Finite difference basics are summarized and various applications shown in course note format, accessible to sponsors via the WWW.

INTRODUCTION

This short excursion into the world of finite difference numerical modeling does not intend to be an exhaustive treatise of every possible aspect encountered in the mathematical theory of numerical modeling. It rather is aimed at highlighting some important problems and techniques encountered in this field.

Traditionally the description of physical systems is based on a set of partial differential equation. This mathematical description allows to find analytical solutions if the medium is not too complex, i.e. the medium consists of simple structures. A great deal of understanding comes from simplified analytical solutions.

However, if the medium becomes too complex, as is often the case for the realistic exploration and production oriented seismic problems, then numerical solutions are the only way to find solutions and gain understanding of the physical system. Highly heterogeneous or randomly distributed media parameters are only a few examples of physical systems with increased complexity.

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METHOD

My aim is to show the strength and limitations of numerical methods for solving partial differential equations by giving realistic examples. Starting with a general overview I start with simple one-way 1D wave equations and proceed via the description of heat transfer in two and three dimensions to the visco-elastic anisotropic 3D wave equation. I show time domain solutions for all those wave equation modeling problems.

The main thrust is on seismic wave propagation in complex media with applications to earthquake and fault zone modeling and emphasis on exploration and production seismic modeling. I show a flexible software library to model media with elastic, anisotropic and viscous behaviour. In addition, the freedom to place an arbitrary number of point or distributed sources of displacement, pressure or acceleration allows the investigation of novel acquisition geometries in addition to standard surveys.

Understanding basic wave propagation effects can help in interpreting complex reflection responses from heterogeneous media and in identifying events in the pre-stack seismic data. Forward modeling can be used directly in wave field processing and inversion procedures, as well as for generating calibration and test data for specialized processing algorithms. Survey design issues can be resolved in visualizing complex full wave form propagation effects to determine subsurface coverage and illumination.

FUTURE CHALLENGES

This is a non-exhaustive list of objectives for further research and development for full wave form modeling techniques.

The link of fluid flow properties to seismic wave propagation in reservoirs, should increase reliability in reservoir properties estimation and production forecasting as well as history matching. Porous and permeability effects need to be included efficiently.

Another important research direction is the efficient multi-source 3D full wave form modeling for complex heterogeneous reservoirs. Currently asymptotic ray tracing methods dominate this area of application, due to the computational efficiency necessary to model full pre-stack data sets and Green's Functions. However full wave form responses cannot realistically be achieved by current asymptotic techniques.

To test processing sequences and aid in interpretation of recorded complex data sets necessitates the ability to efficiently generate selective wave field estimates. Such that assumptions of processing algorithms and inversion procedures can be tested and objective error measures be quantitative assessed based on true full and selective wave field responses.

For applications such as time lapse monitoring efficient modeling studies are highly desirable. Varying a complex target area in a complex host medium would allow modeling studies without the need to recompute an entire multi-source seismic response for

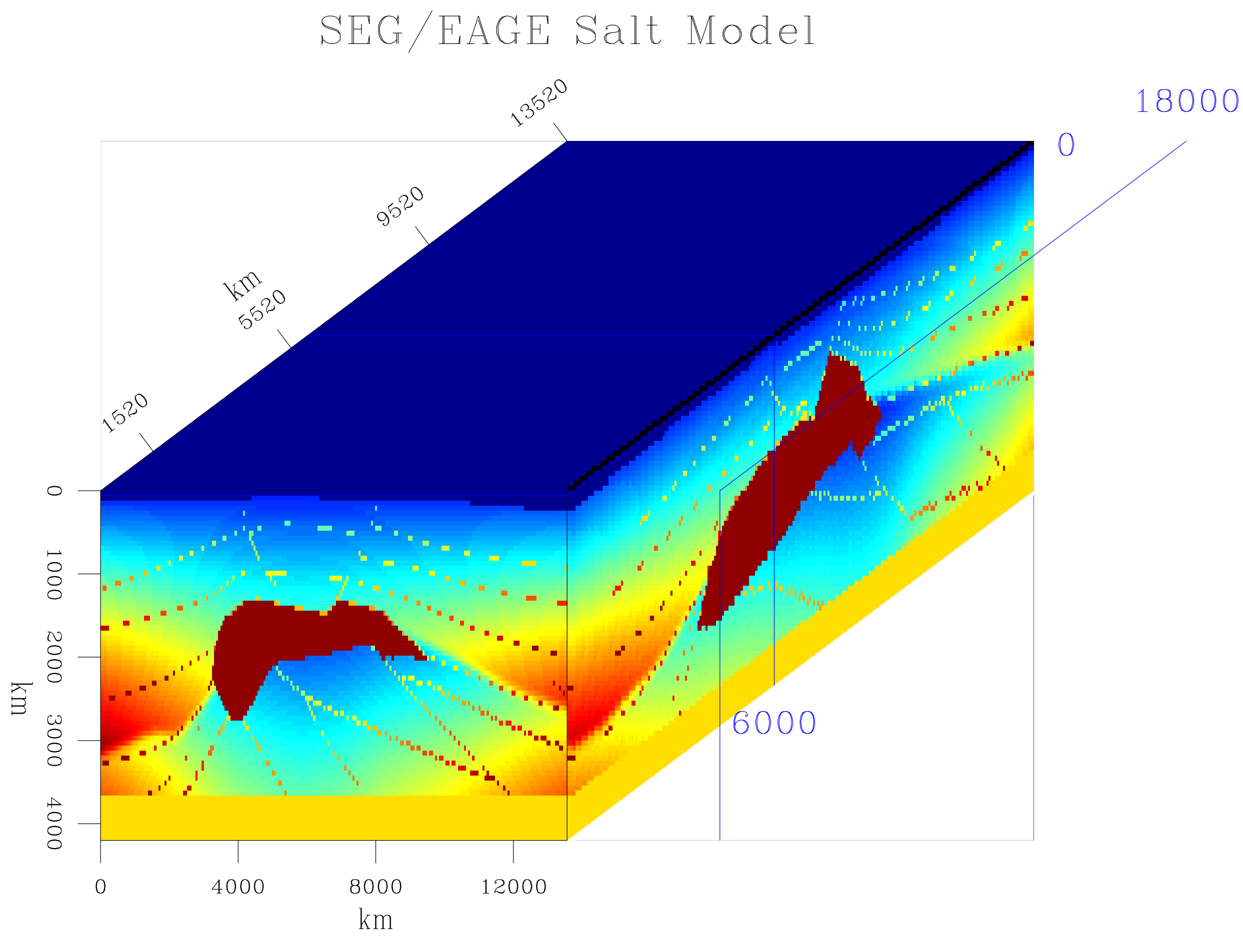

Figure 1: Elastic SEG/EAGE Salt Model.

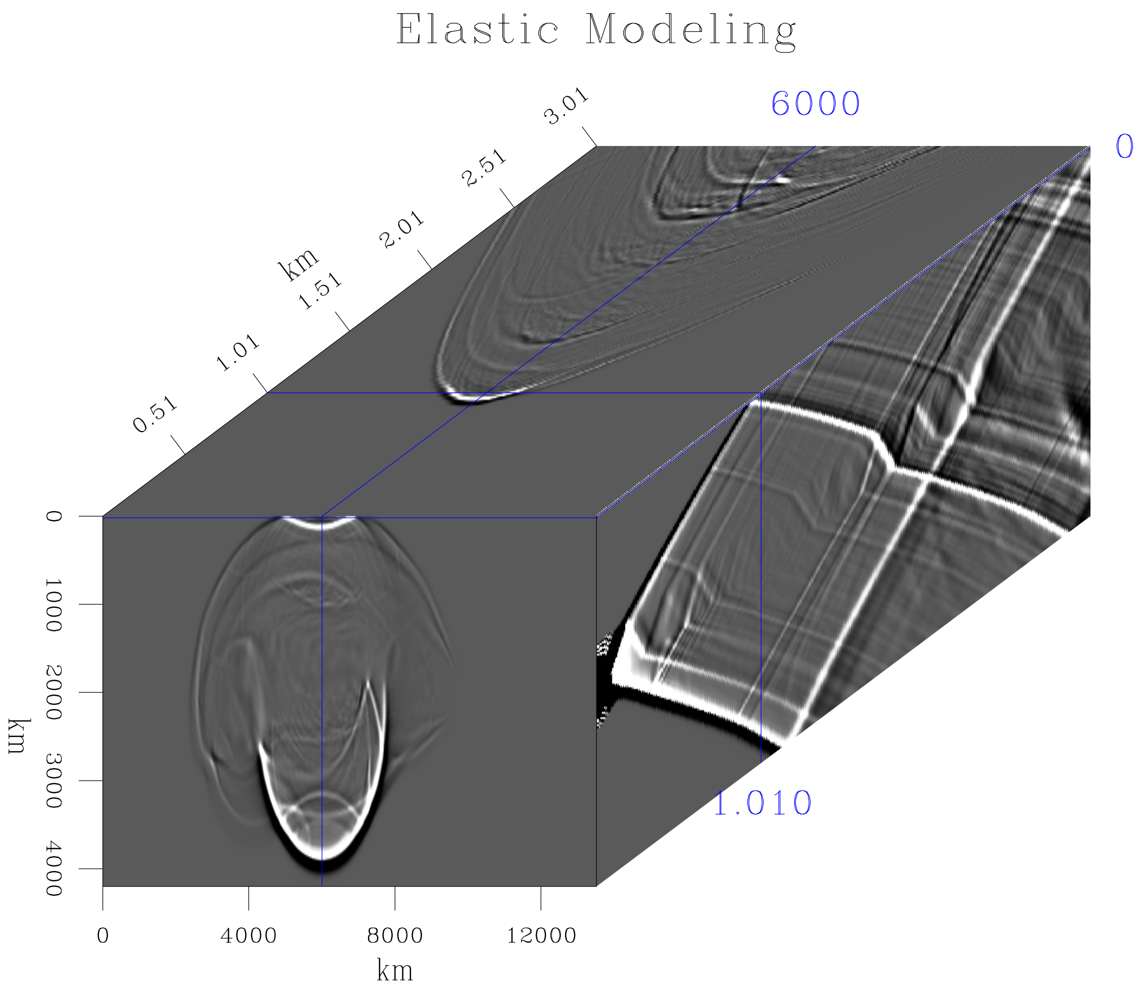

Figure 2: Elastic wave field in the Salt Model.

each change of target properties.

REFERENCES

M. Karrenbach, 1997, Modeling of Physical Systems, Course Notes.