Computational Seismology in the “Exploration” Industry

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Schlumberger Cambridge Research

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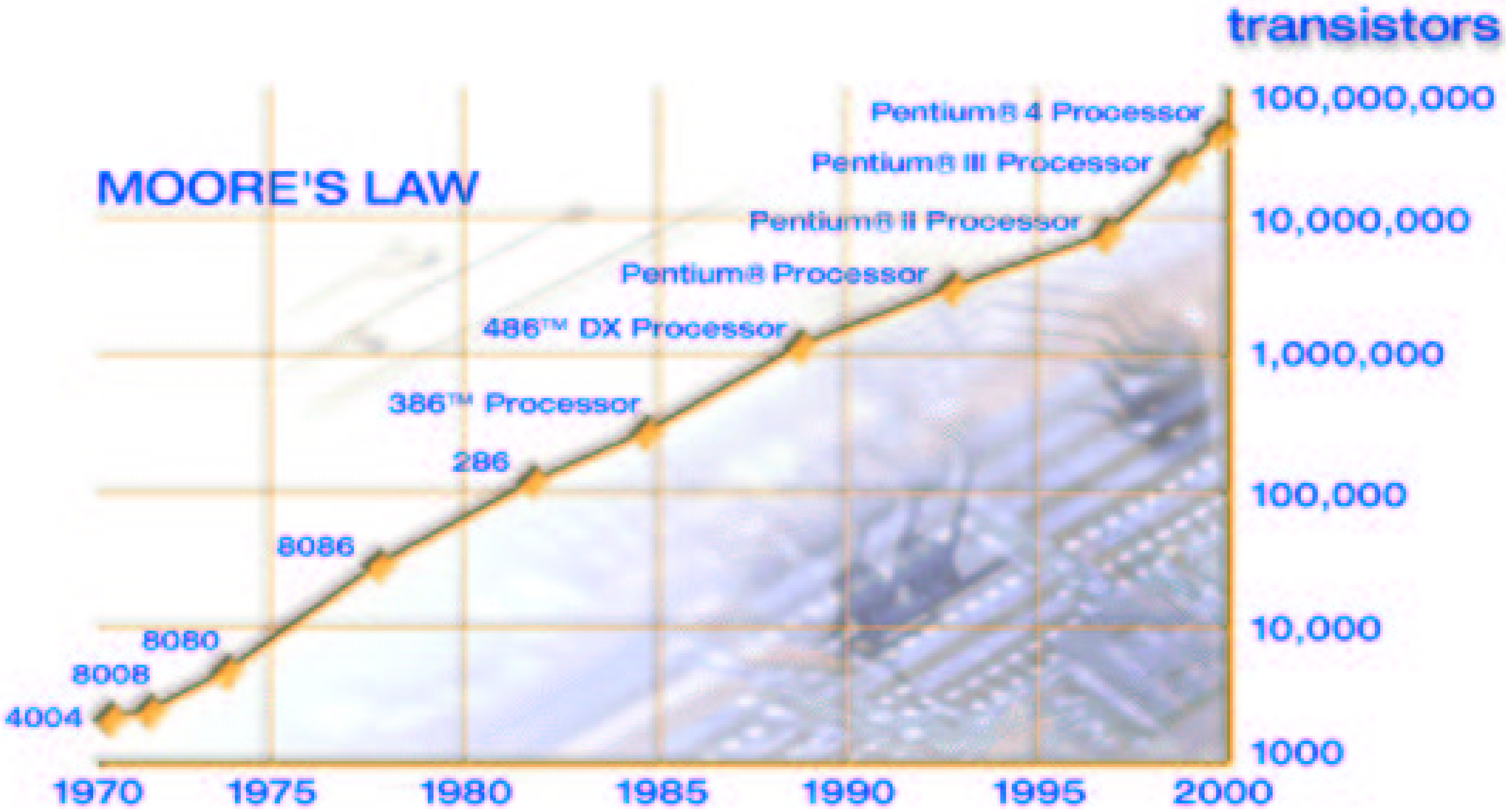
- Around 100 permanent staff in 3 departments

- Department of Geophysics
  - 15 permanent staff + 5 postdoc’s
  - Research from acquisition through to imaging and inversion applications

Outline

- Modelling needs in industry
- Examples of how (FD) modelling is used in research at SCR
  - Modelling the effects of a rough sea on marine seismic recordings
  - FD-injection - An efficient method for calculating finite-difference seismograms after model alterations
- Conclusion and anticipation for the future



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The Challenge for the "Exploration" Industry

- Objectives:
  - Simple structures are well understood
  - Structurally complicated scenarios is the challenge (sub-salt, faults, carbonate environments, etc.)
- Typical size of a 3D seismic problem
  - Source positions: O(100,000)
  - Receiver positions: O(10,000,000)
  - Model size: 1000x1000x1000 (100 GByte in FD)
- Turn-Around Time can be critical…
- CPU, memory and disk space are issues

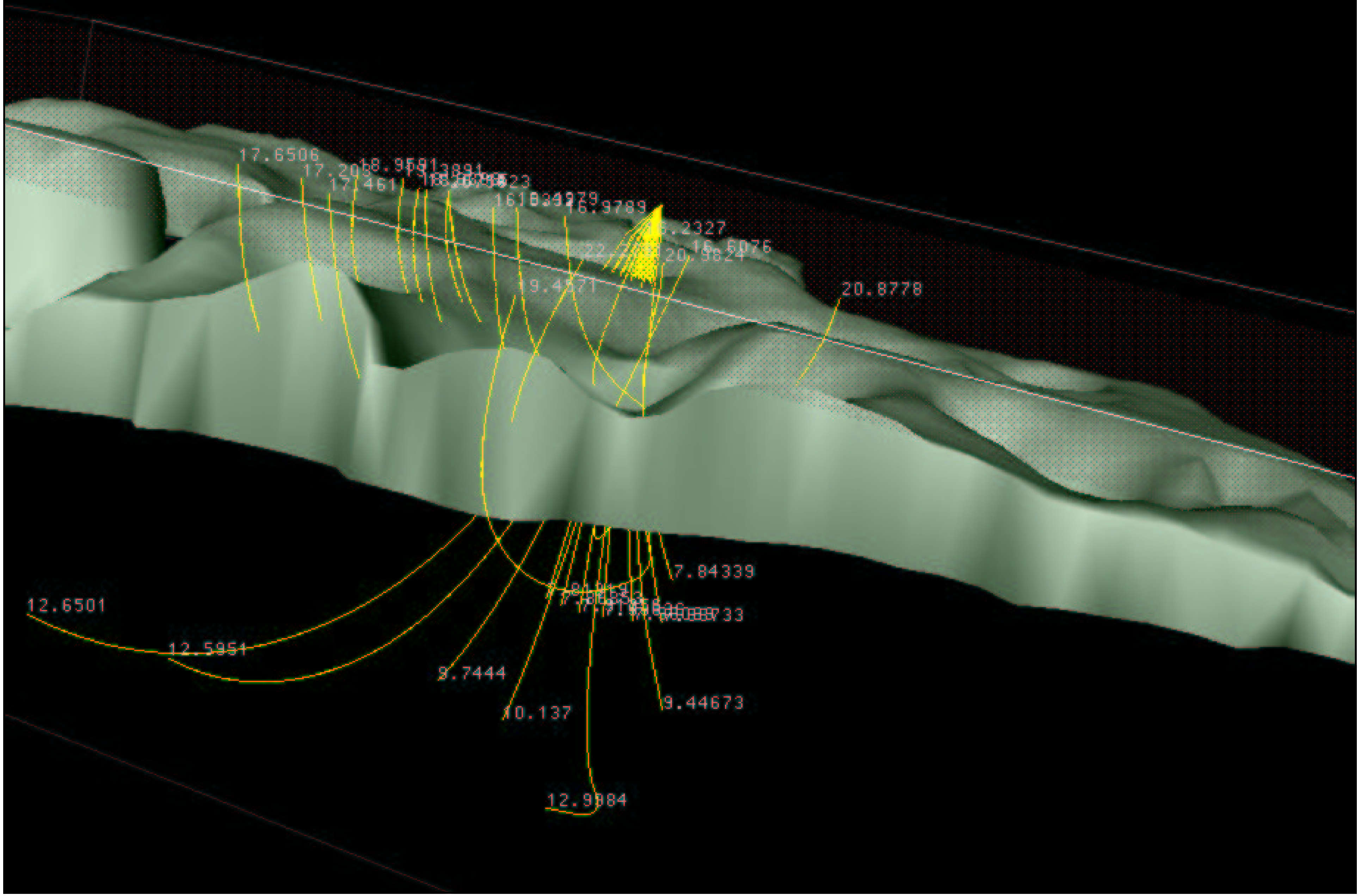
Seismic Data Modelling

- Wide range of applications with different requirements in terms of cost, complexity and accuracy
  - 3D and 4D Survey Evaluation and Design (SED)
  - Model-based processing (e.g., noise attenuation)
  - Migration and velocity-model building (imaging)
  - Model validation
  - Parameter inversion for reservoir characterization
  - New inversion and imaging techniques
  - Computing synthetic data sets for research and testing new algorithms

Established modelling methods I

- Ray-based modelling
  - Velocity model building, tomography, migration
  - Born, Kirchhoff and Maslov extensions can extend use to more sophisticated waveform inversion applications
- Layered-media modelling (Kennett)
  - Model-based processing, model validation, parameter inversion for reservoir characterization, new inversion and imaging techniques, testing new algorithms
- Full one-way wave equation solvers (e.g., FD)
  - Wave equation migration

TraceRay



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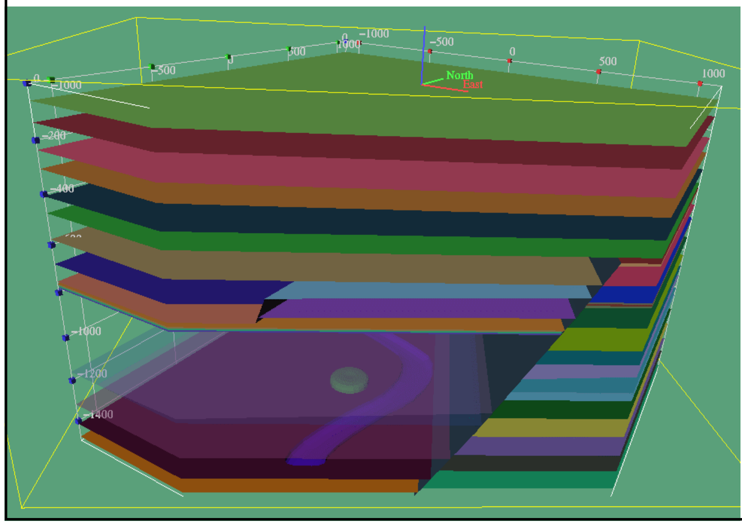
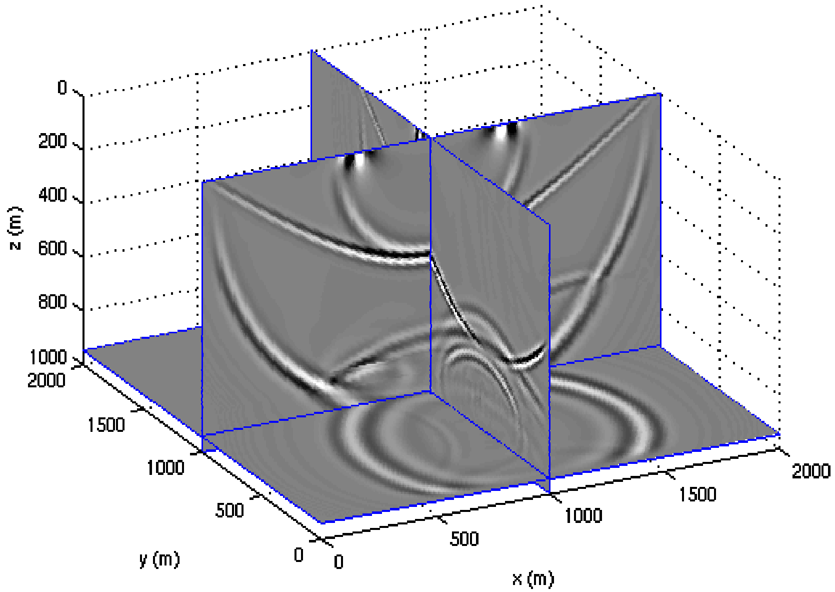
- Full one-way wave equation solvers (e.g., FD)

Established modelling methods II

- Full two-way wave equation solvers (FD, spectral methods)
  - SED, model-based processing, model validation, *parameter inversion for reservoir characterization, new inversion and imaging techniques*, testing new algorithms





Non-established modelling methods

- Advanced FD and FE modelling methods (e.g., Geller and SEM)
  - – Efficiency only for high accuracy – generally not a requirement for the industry
- Spectral elements, hybrid modelling methods, phase screens
  - – Problematic issues mainly related to model representation and interaction
  - – Huge potential if these issues could be addressed

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Finite-difference method

- Explicit solution of the viscoelastic stress-velocity formulation of the wave equation (Robertsson et al., 1994)
  - 2nd order accurate in time, 4th order accurate in space
  - Staggered grid (Madariaga, 1978; Virieux, 1986; Levander, 1988)
  - Models acoustic/elastic interfaces accurately (Mosco et al., 2002; van Vossen et al., 2002)

Finite-difference method

- Free surface with topography (Robertsson, 1996)
  - Has been used studies of near-surface effects and scattering from rough seas
  - Difficult to assess accuracy but has been successfully tested against other methods
  - Requires 3-4 times denser sampled wavefield (15-20 grid-points per wavelength)
- Grid-refinement (Robertsson and Holliger, 1997)
  - Three times finer grid near sea surface

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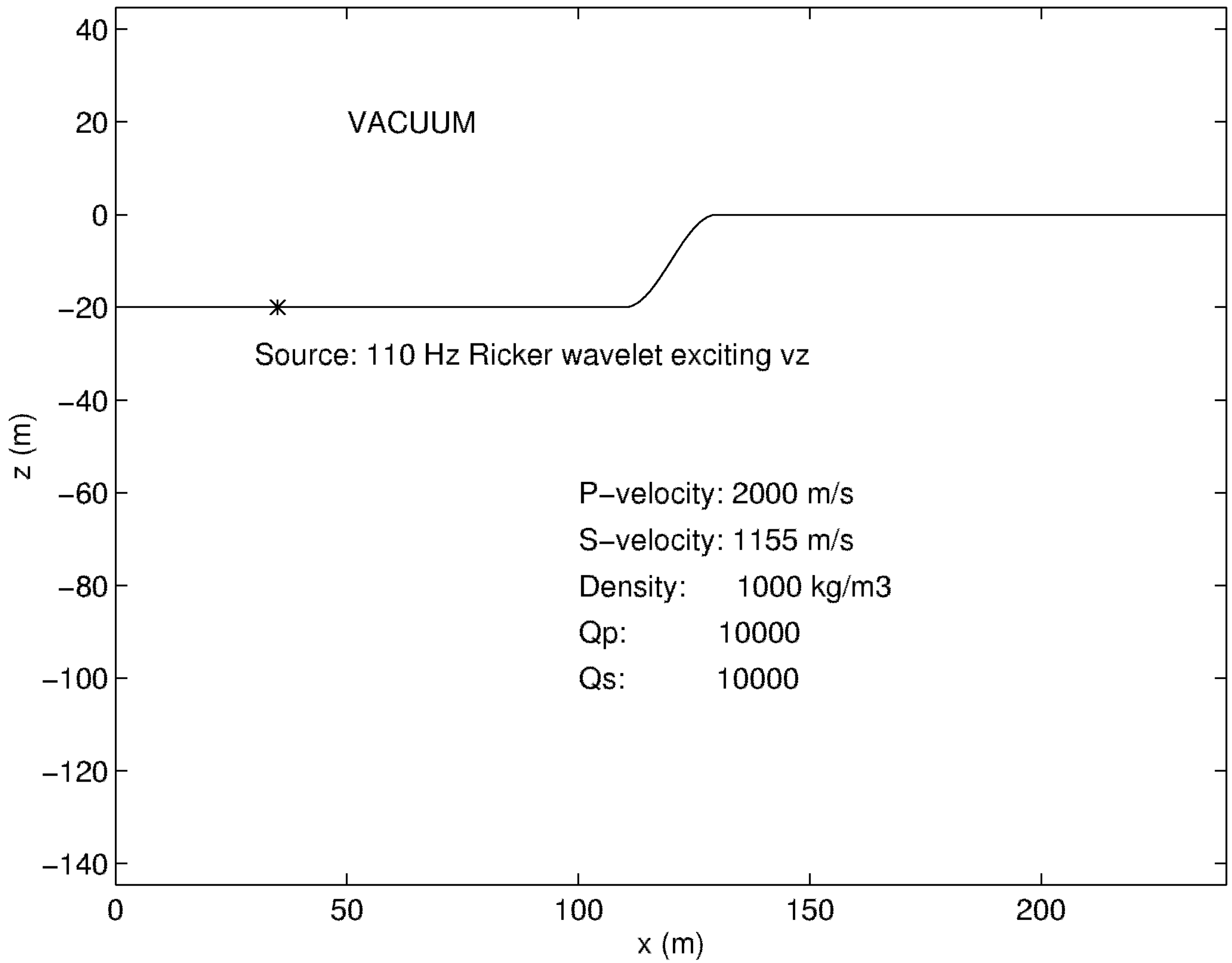
Free-surface topography in FD



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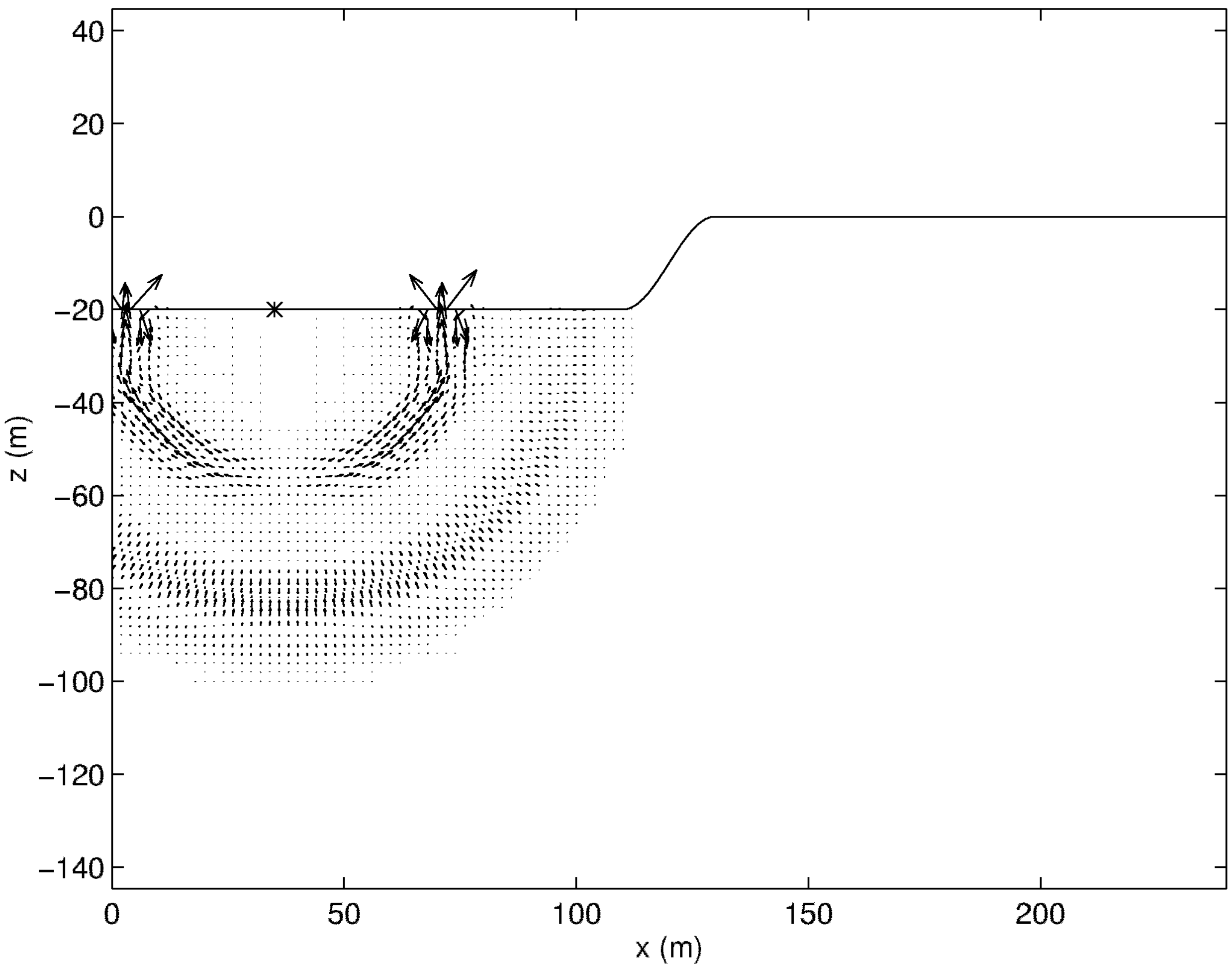
Free-surface topography in FD



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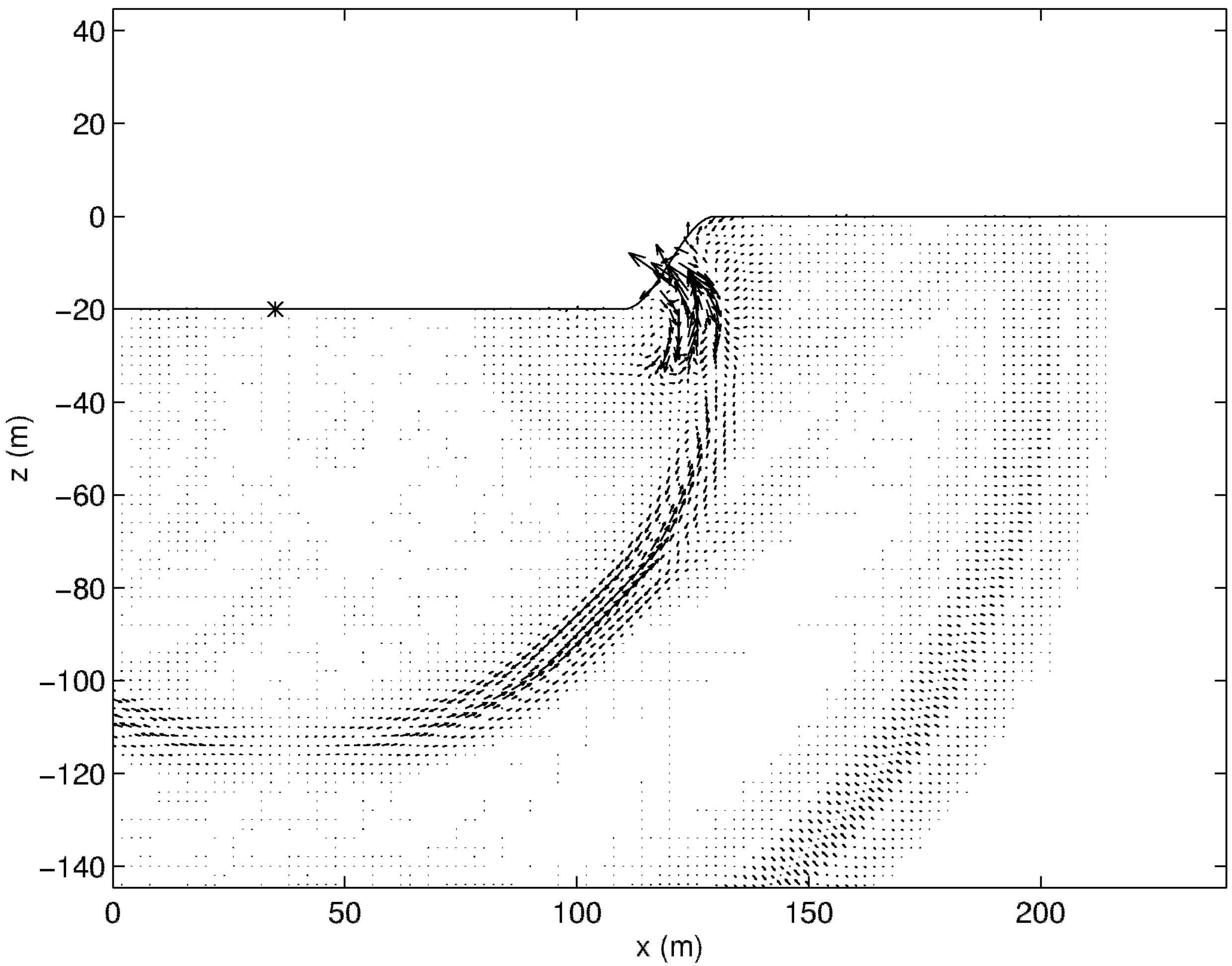
Free-surface topography in FD



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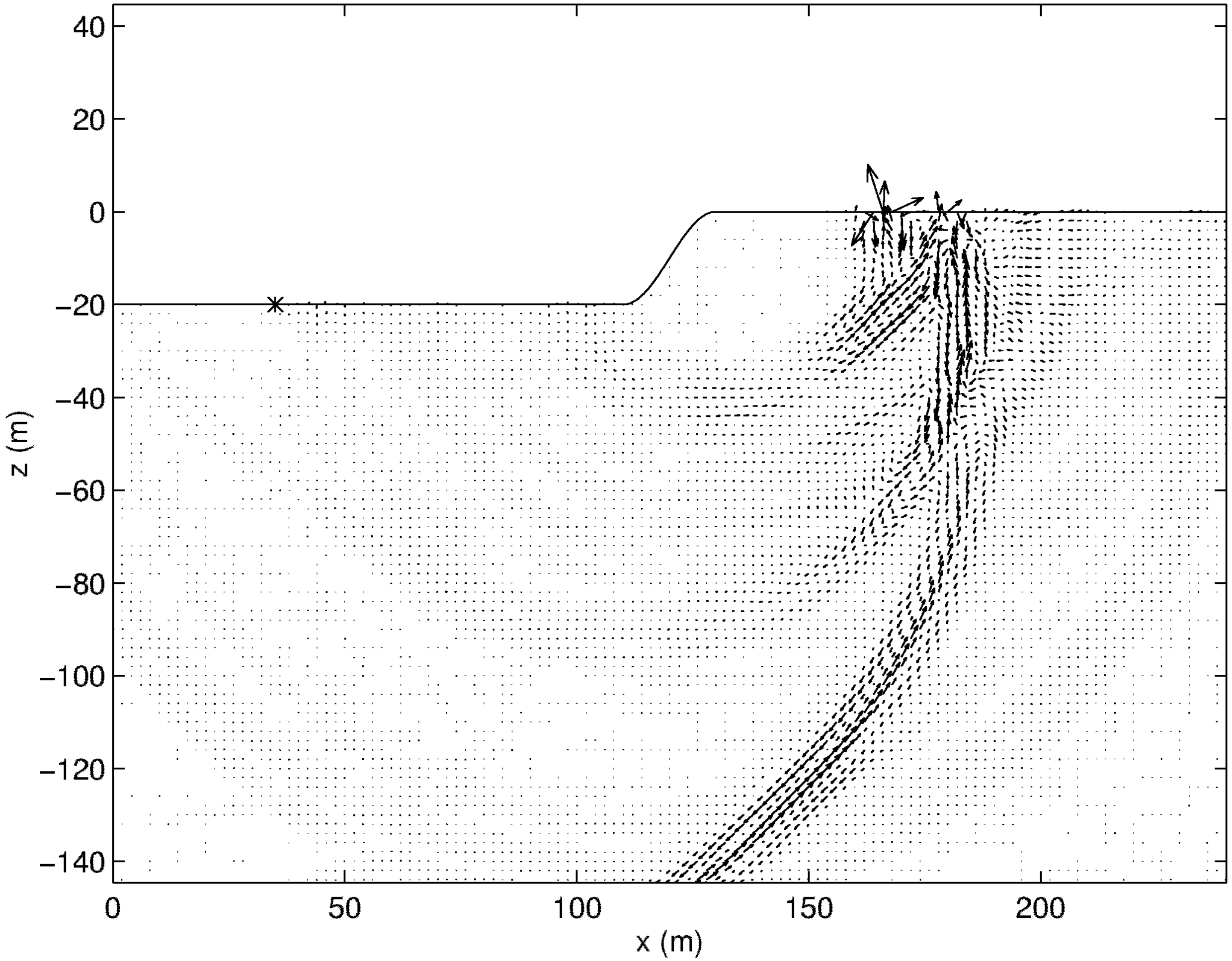
Free-surface topography in FD



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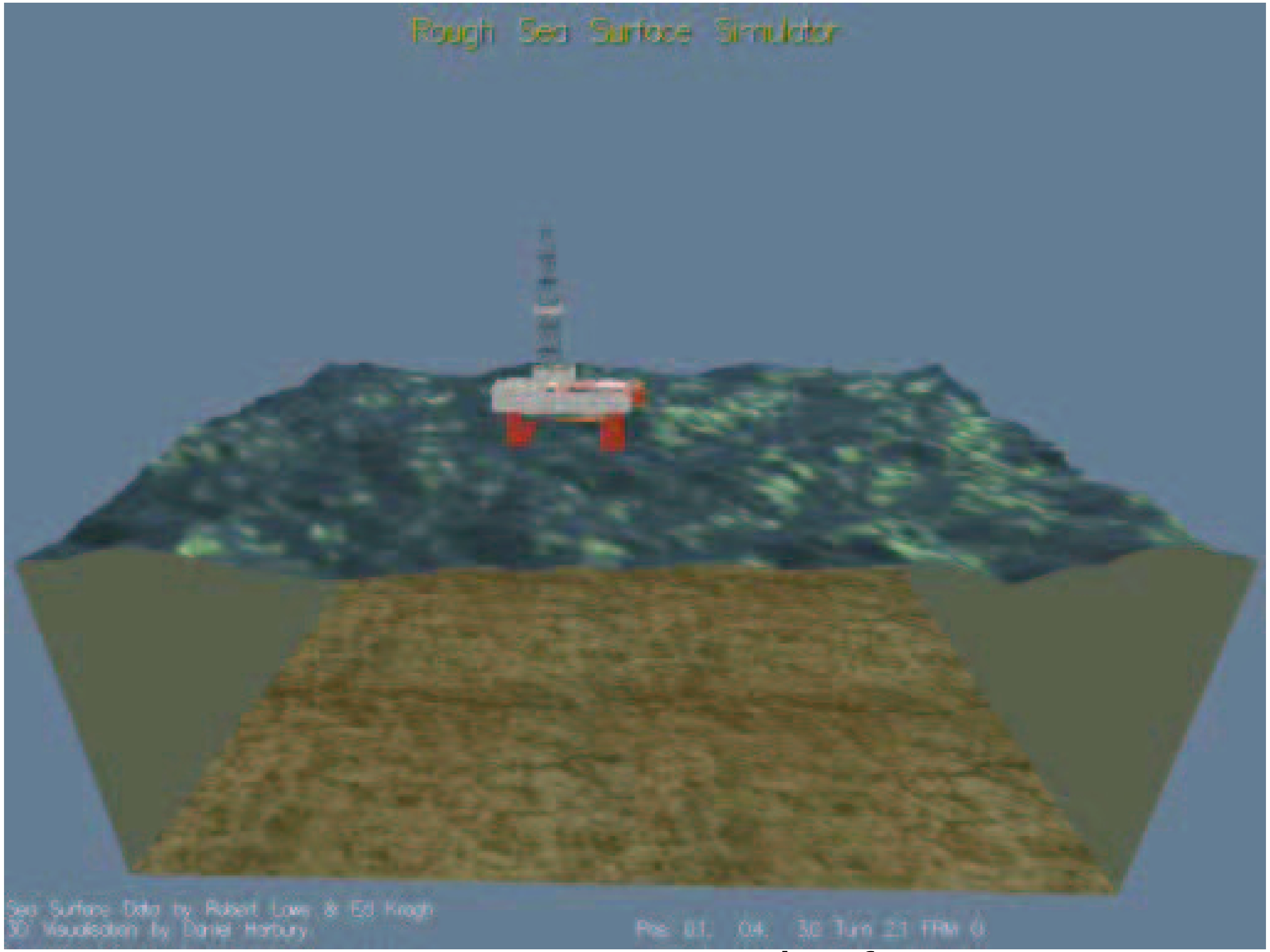
Rough sea surface simulation



- 256m square patch of sea
- 4m SWH (vertical exaggeration = 2)

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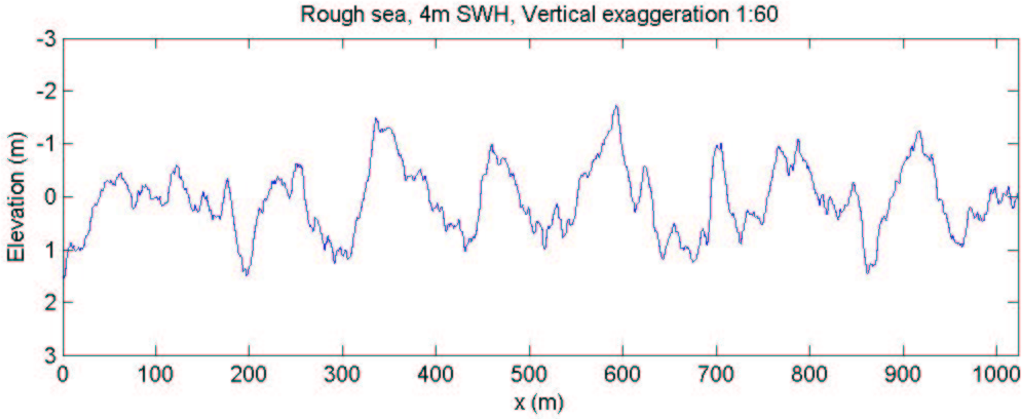
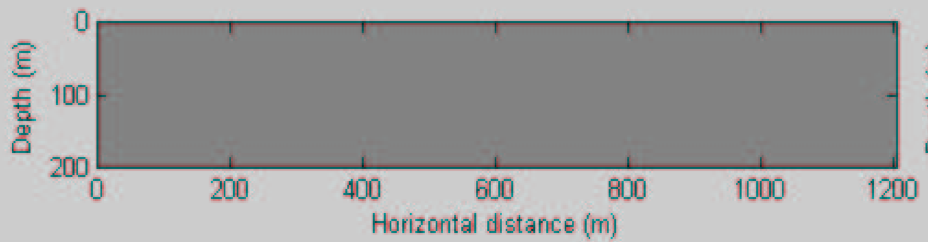
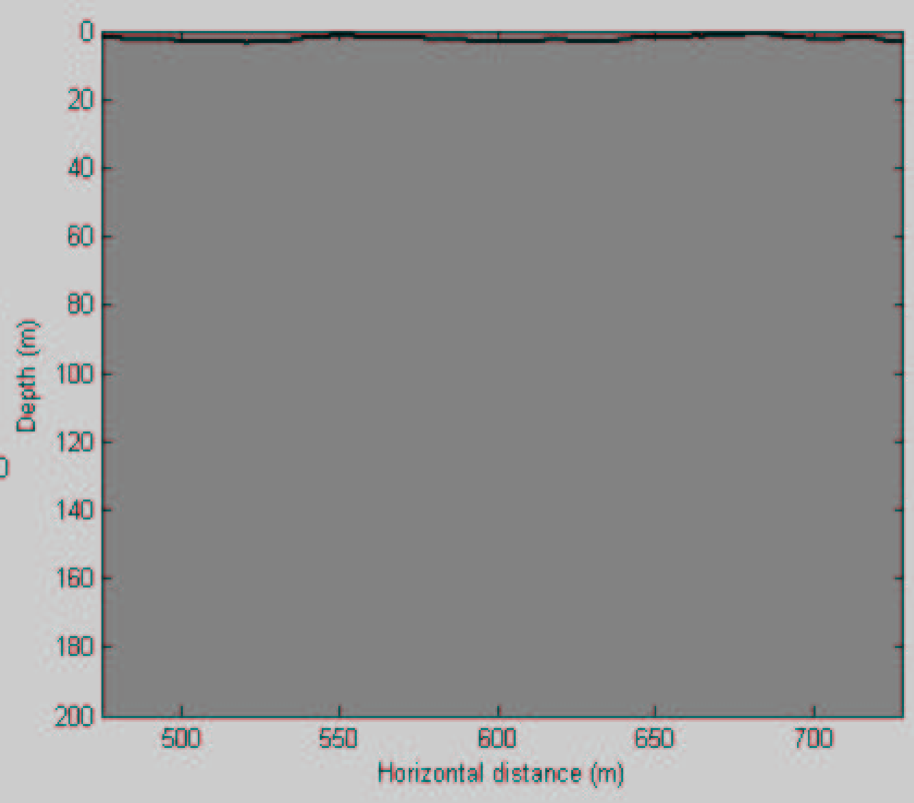
FD Modelling of a Rough Sea

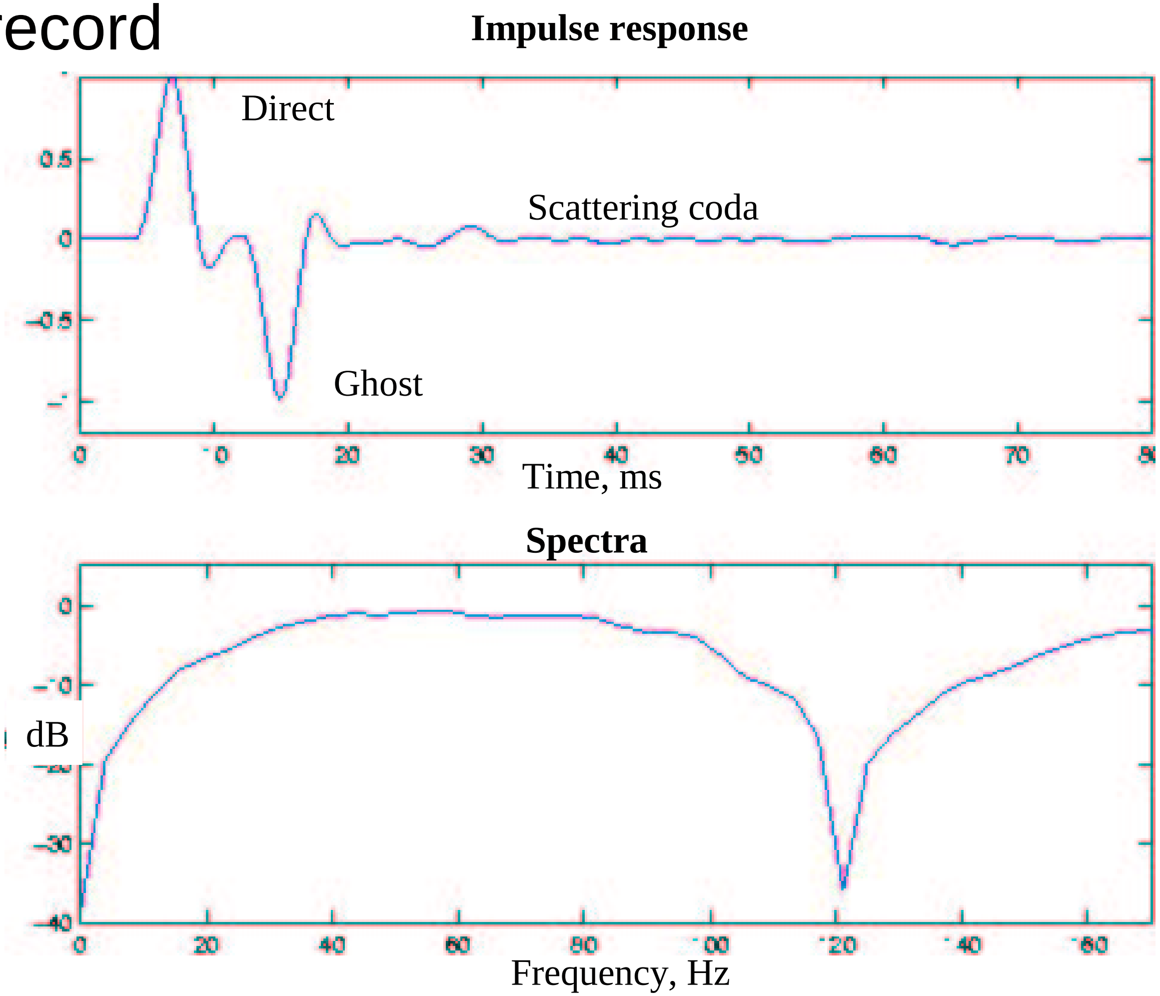






The dynamic receiver ghost

The sea moves considerably during the seismic record



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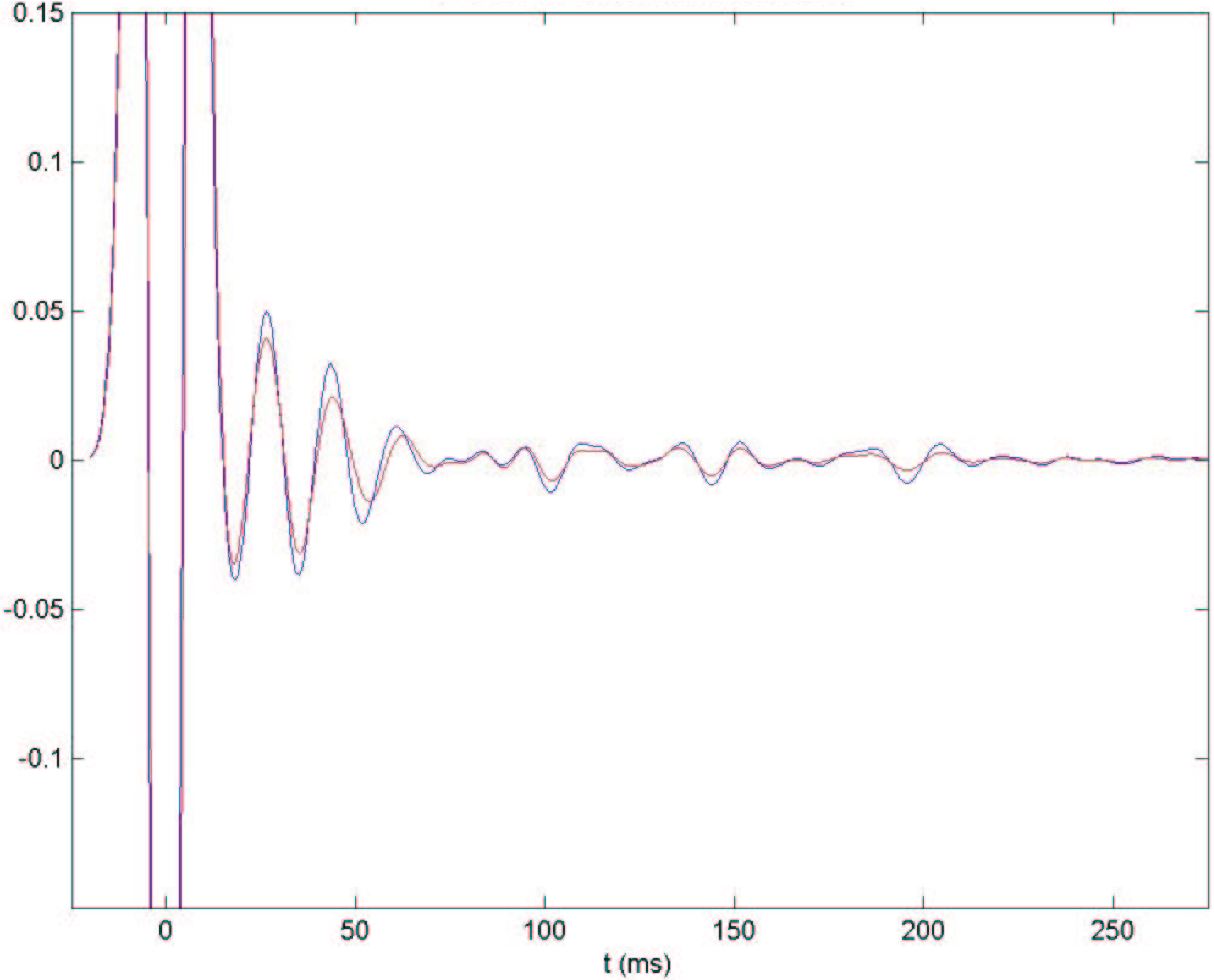

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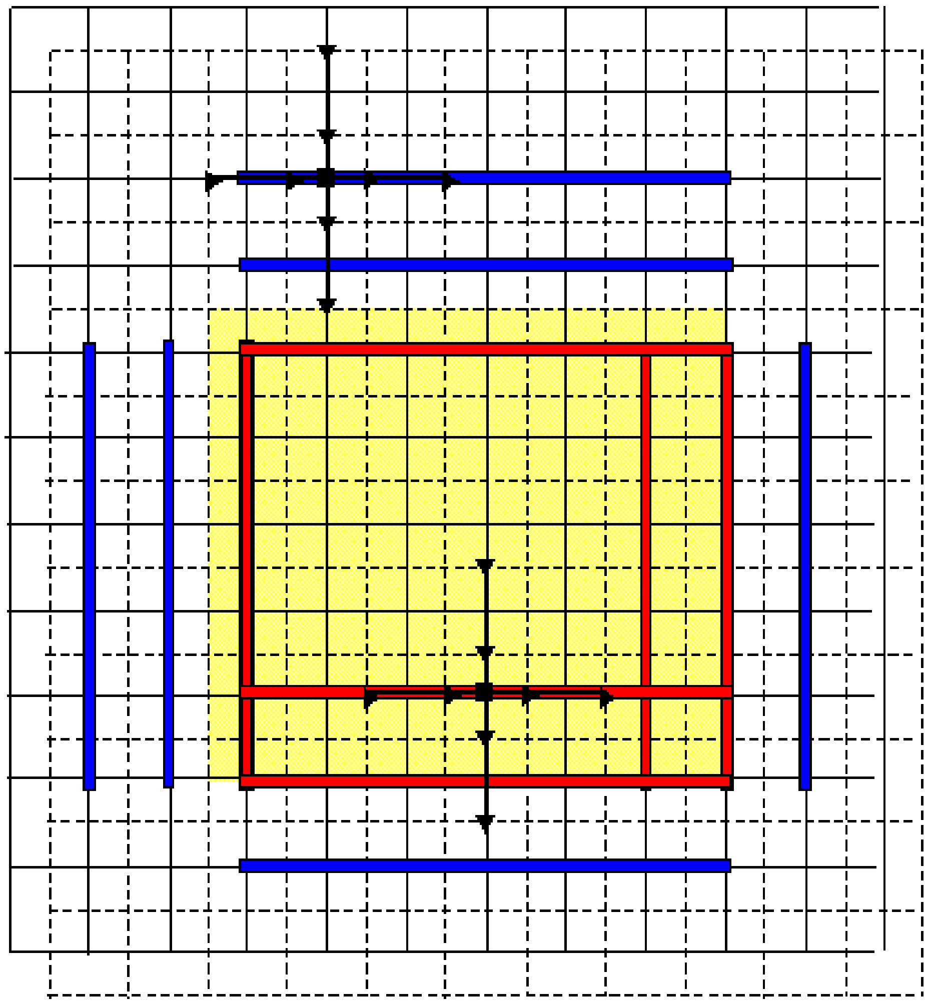
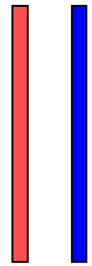
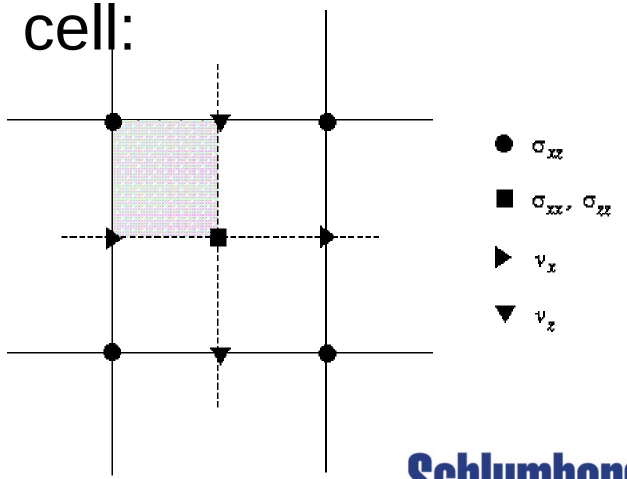
FD Hybrid Modeling

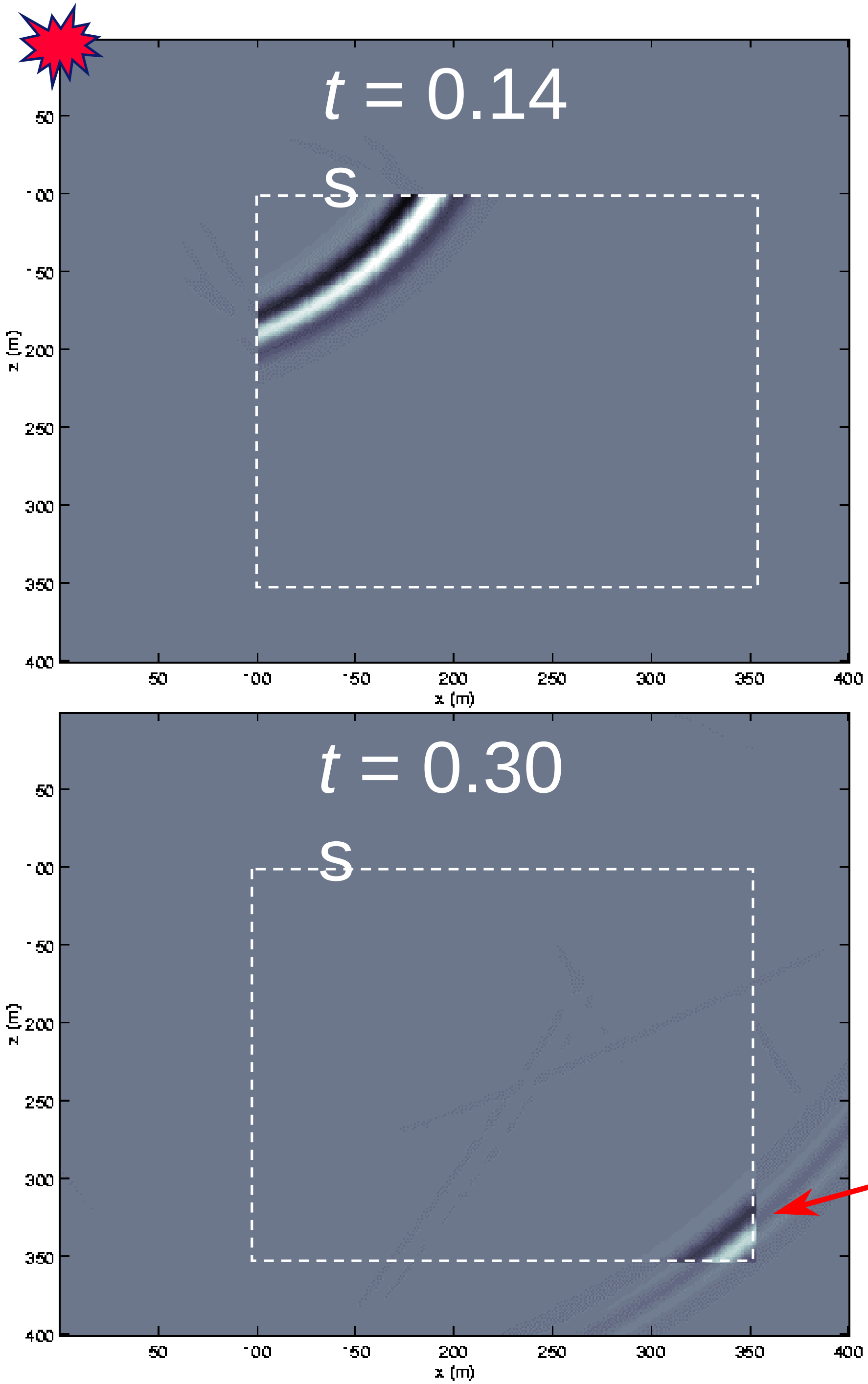


Grid cells where parts of FD stencil intersect discontinuity:



Staggered FD grid cell:





- Hybrid modeling: Analyt. - FD
- Injection along dashed box
- Note mismatch at t=0.30 s

What happens if we generate source wavefield using the same FD technique instead of hybrid technique?

- *FD-injection* based on continuity of superimposed wavefields
  - (1) Record wavefield in initial simulation on *full grid*
  - (2) Only alter model inside injection surface
  - (3) Inject recorded wavefield in simulation on *small grid*
- Wavefield outside injection surface corresponds to difference before and after alteration

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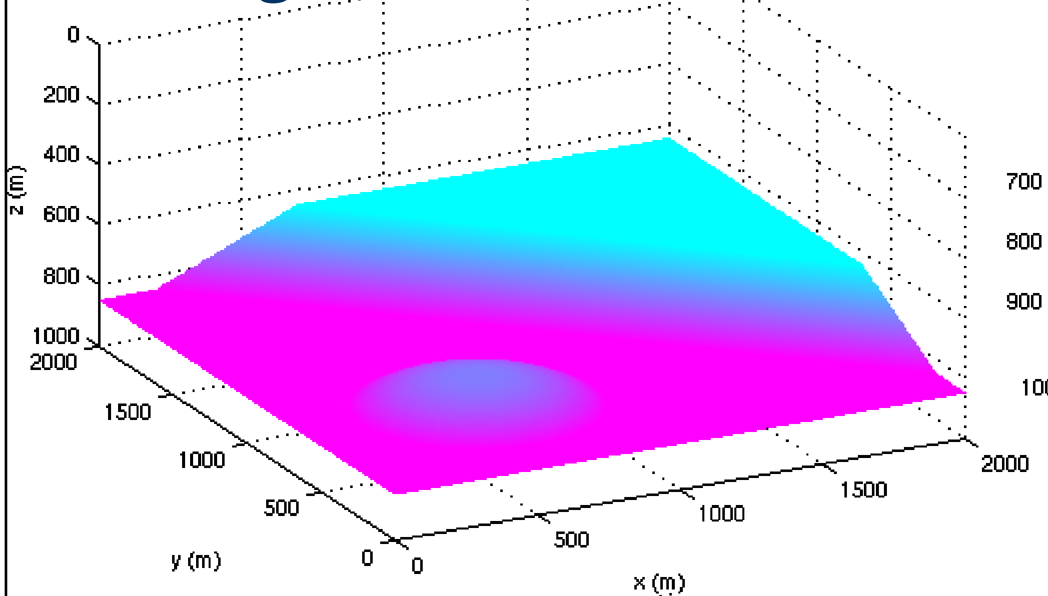
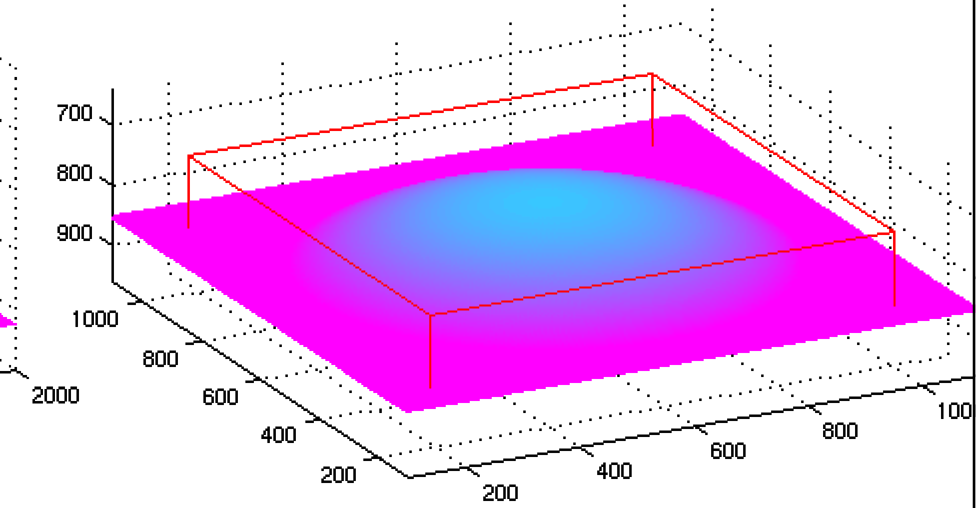
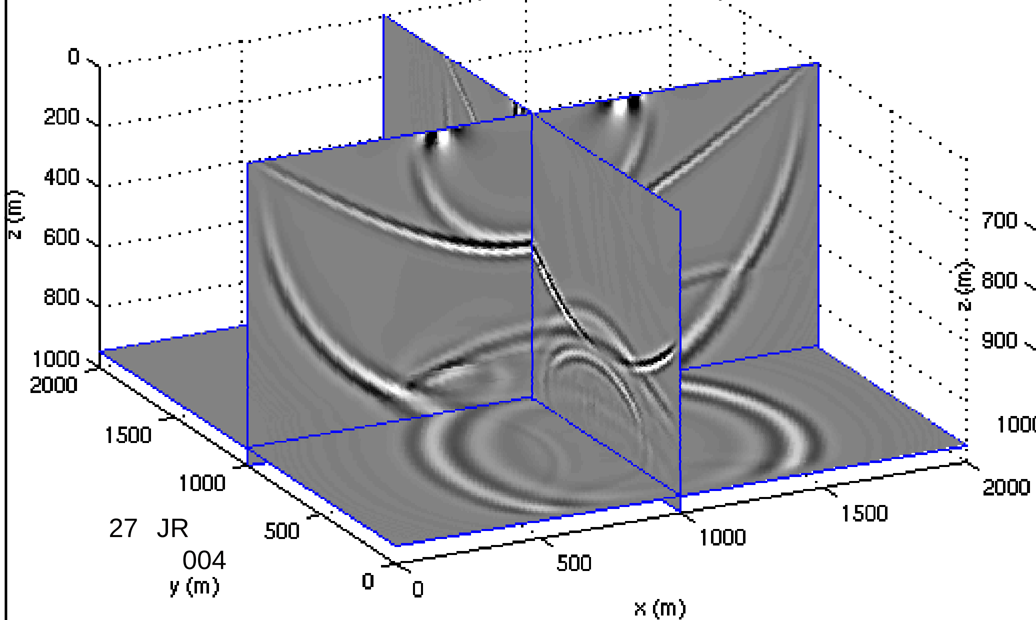
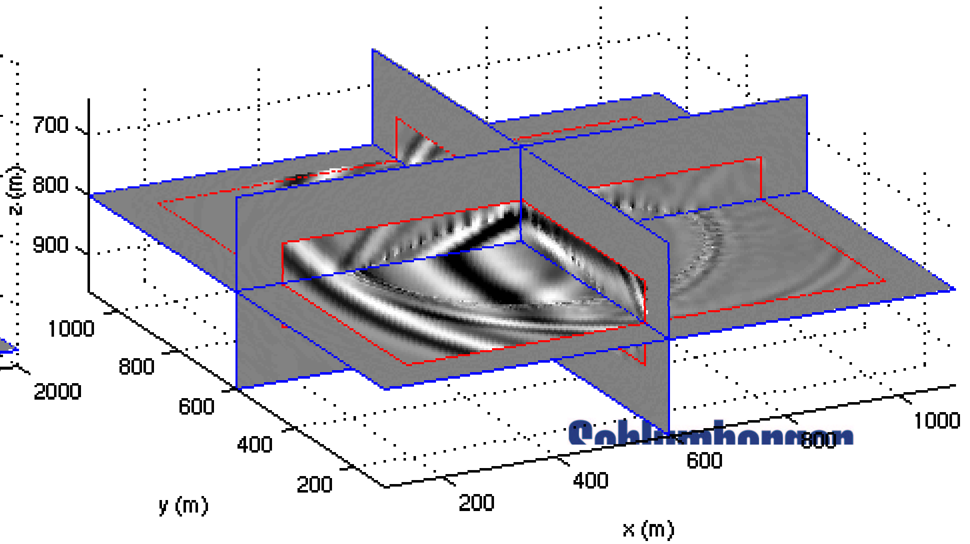
Full grid



Small grid

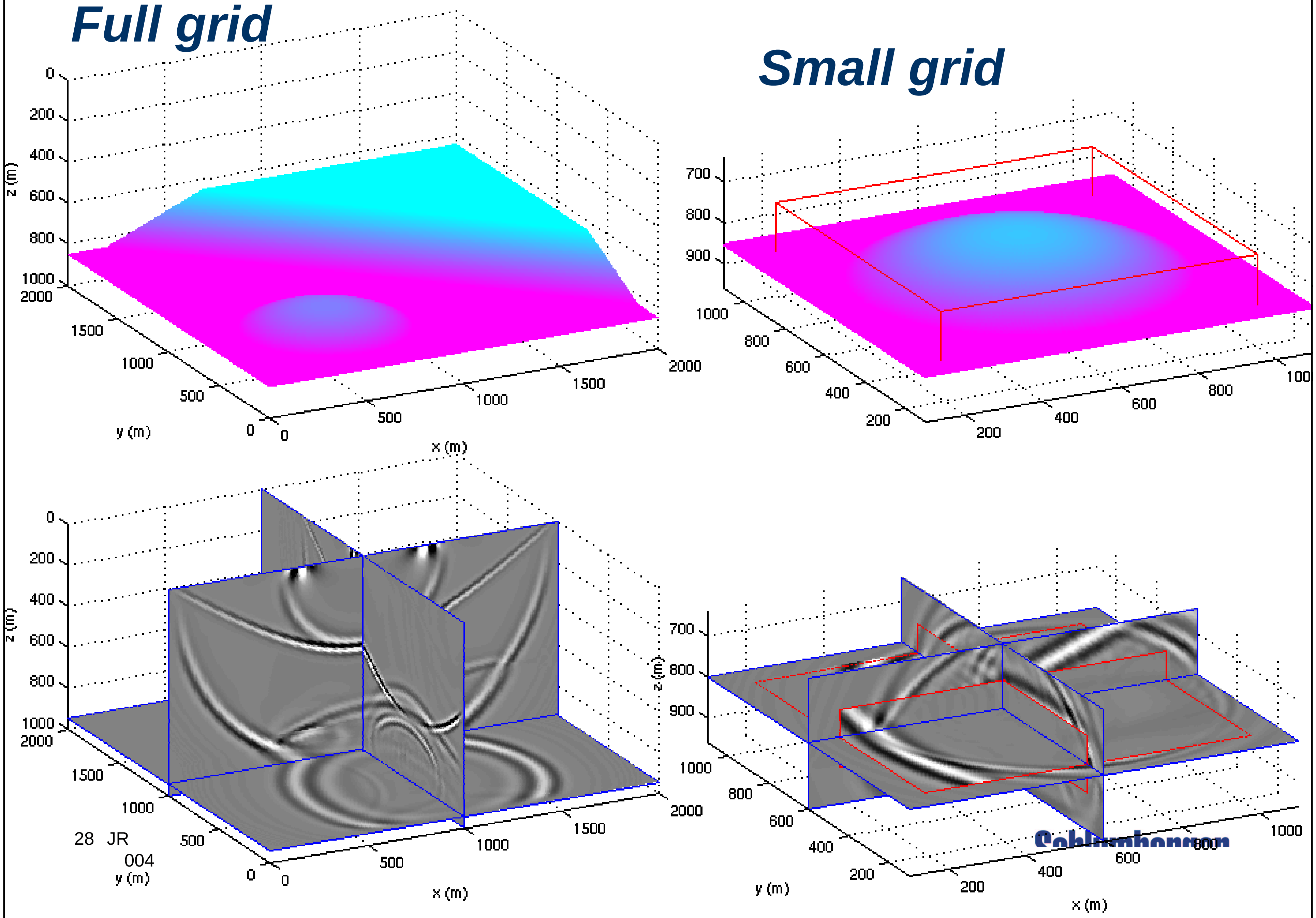






Full grid

Small grid



FD-injection

- Compute seismic responses after model alterations
  - Only small simulations required after initial simulation
  - Synthetic time-lapse example (not shown)
    - Highly accurate, 50-100 times less computations in 2D (estimate factor of 400-700 in 3D)
  - What’s missing?
    - *“Second-order long range interactions”*
      - Part due to interactions of the altered wavefield with the unaltered model outside the small FD sub-grid which propagate back into and are recorded in the sub-grid
      - The interaction of the unaltered wavefield with the full model is completely accounted for

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Conclusions

- Computation less and less the limiting factor
  - now at a point where we can carry out e.g., 3D FD
- Including the whole wavefield (multiples, interface waves, etc.) in seismic inversion increases sensitivity to the Earth parameters
  - currently we discard much of data recorded
- Future modelling techniques
  - Hybrid modelling, spectral elements or anything beyond known technology?
- Flexible, efficient and robust Earth model building environment is a *key enabler*

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