

Towards realistic testing with with RTM and FWI

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CREWES Meeting 2023



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UNIVERSITY OF CALGARY

FACULTY OF SCIENCE

Department of Earth, Energy, and Environment



The gap between industry and academia

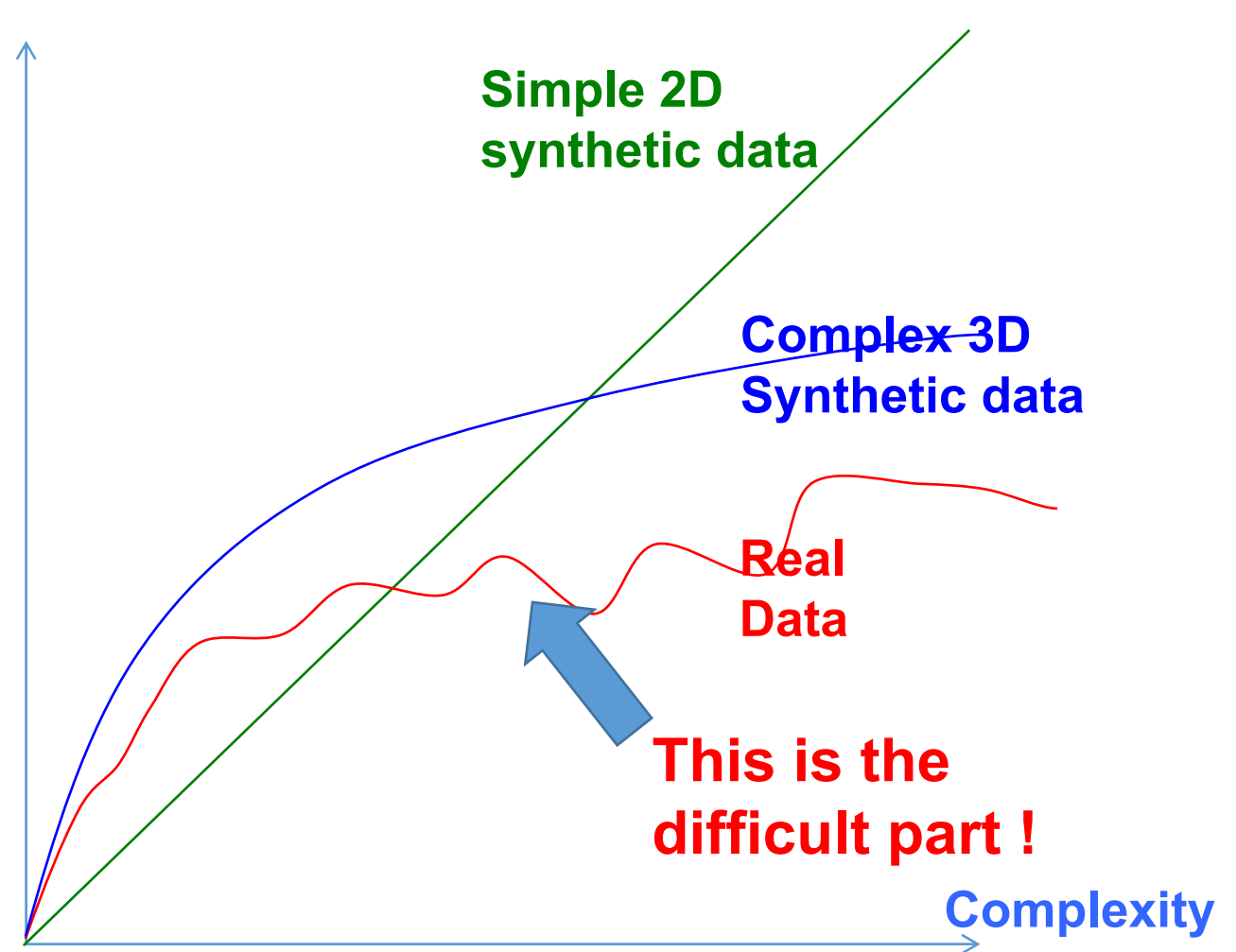
Quality of
results

After decades of seismic research, simple things have already been done
We are forced to work with more complex algorithms to make progress.

In real data increase of complexity does not lead to increase of quality until details are worked out!

The Geophysical Paradox

Complex ideas are usually tested in simple examples
Complex problems are often solved with simple ideas



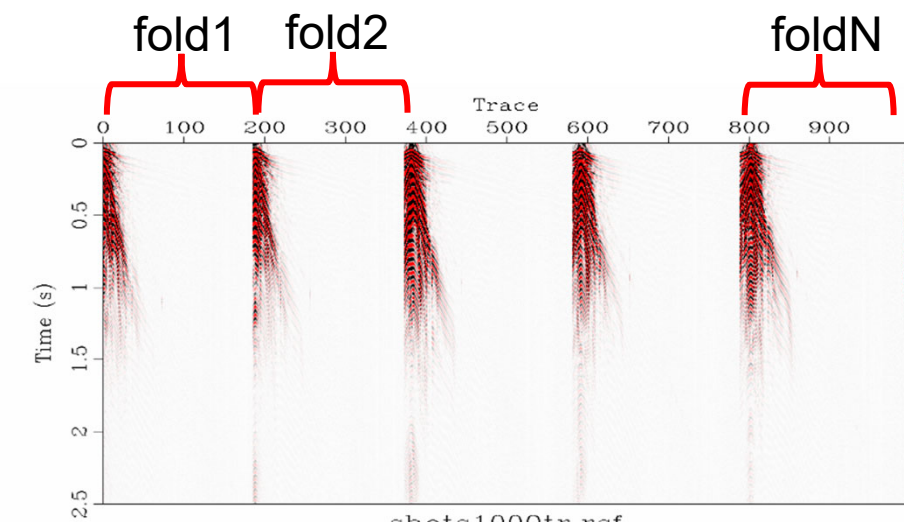
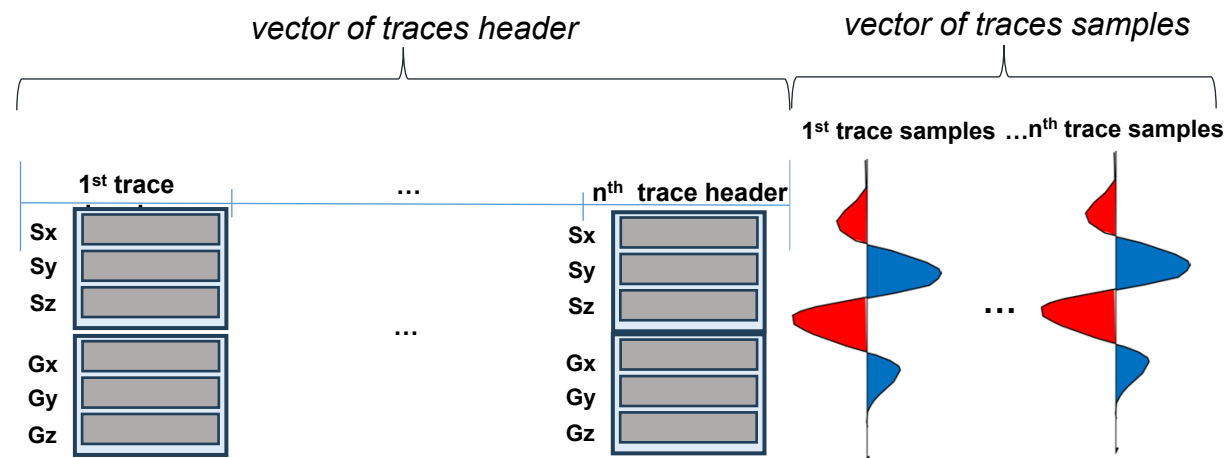
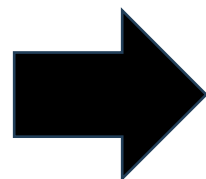
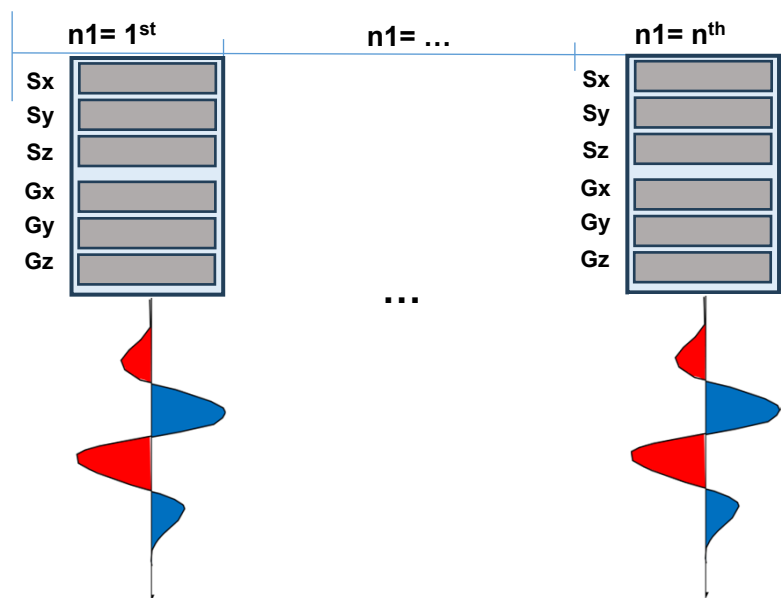


- ❑ Efficient computation through GPUs using CUDA (2020, 2021)
- ❑ Dataflow for real geometries, Modeling, RTM and FWI modules
- ❑ Inverse Crimes in many flavours
- ❑ Examples: Pluto, Foothills, SEAM Overthrust, Physical Data
- ❑ Examples 3D

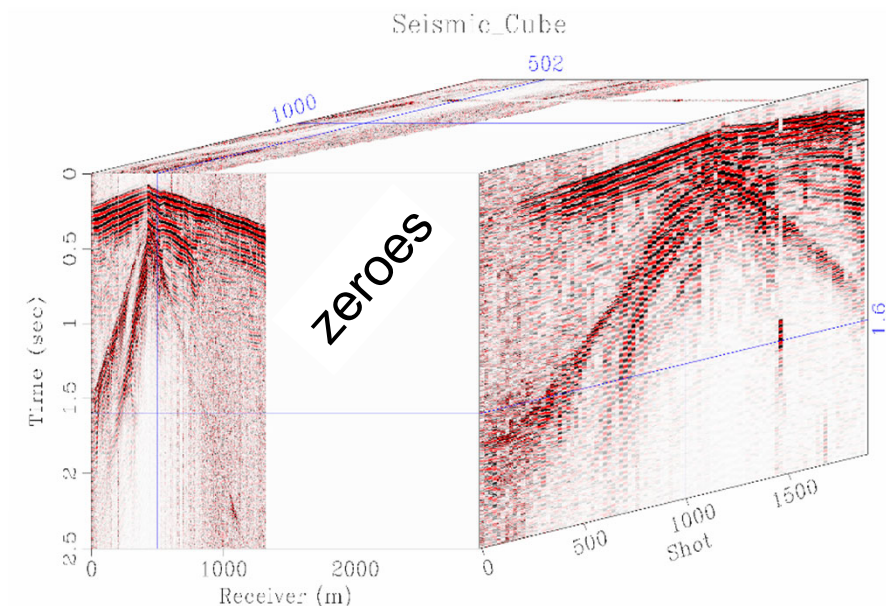


Handling irregular geometries with Madagascar

Segyread < realdata → data + 2 files



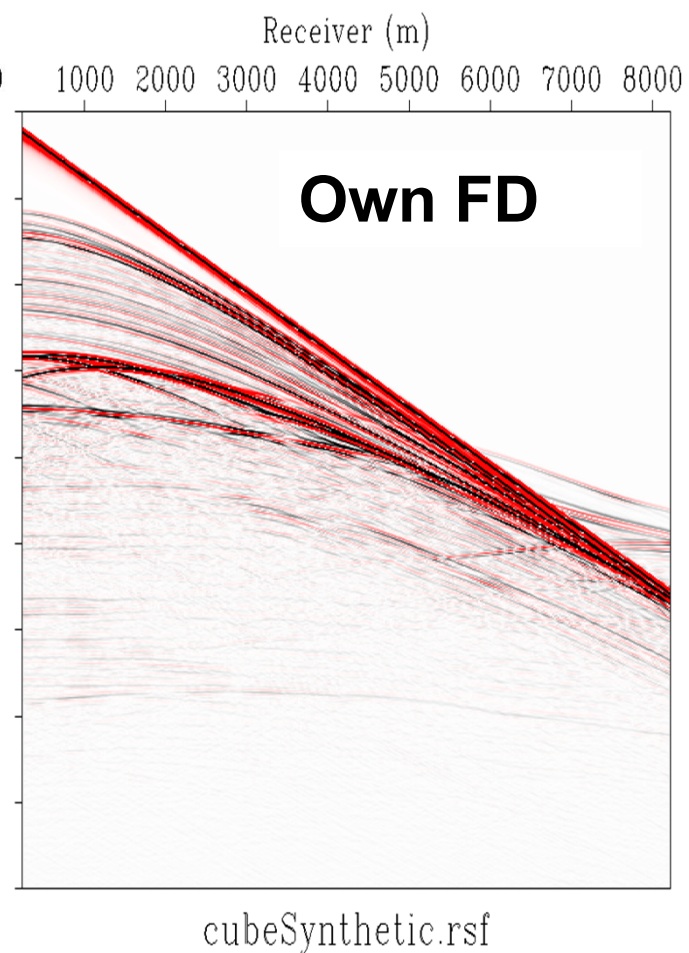
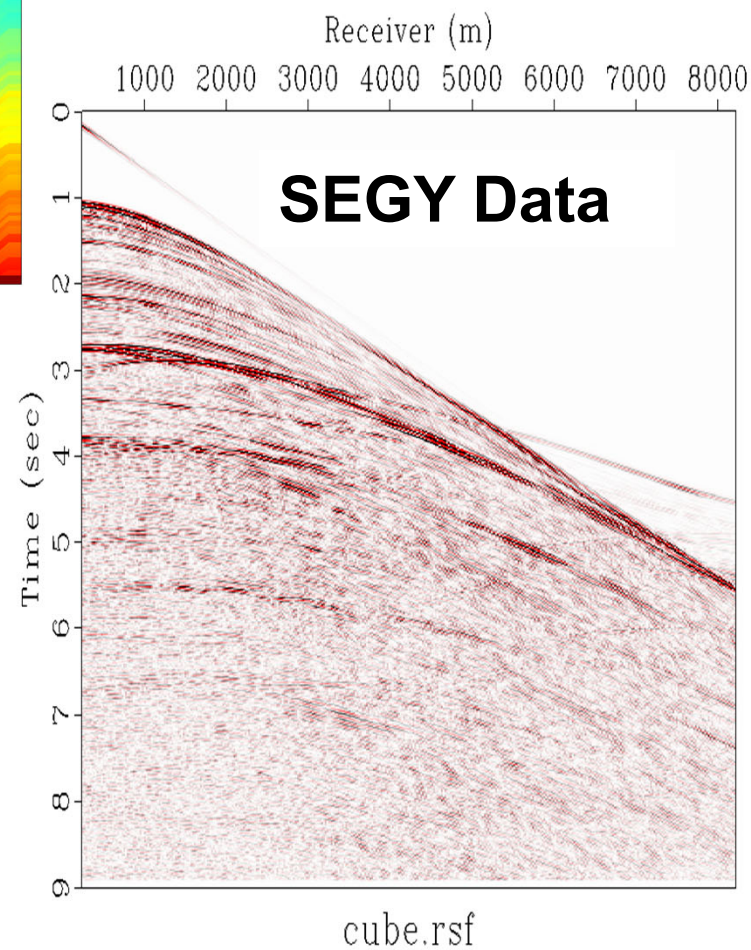
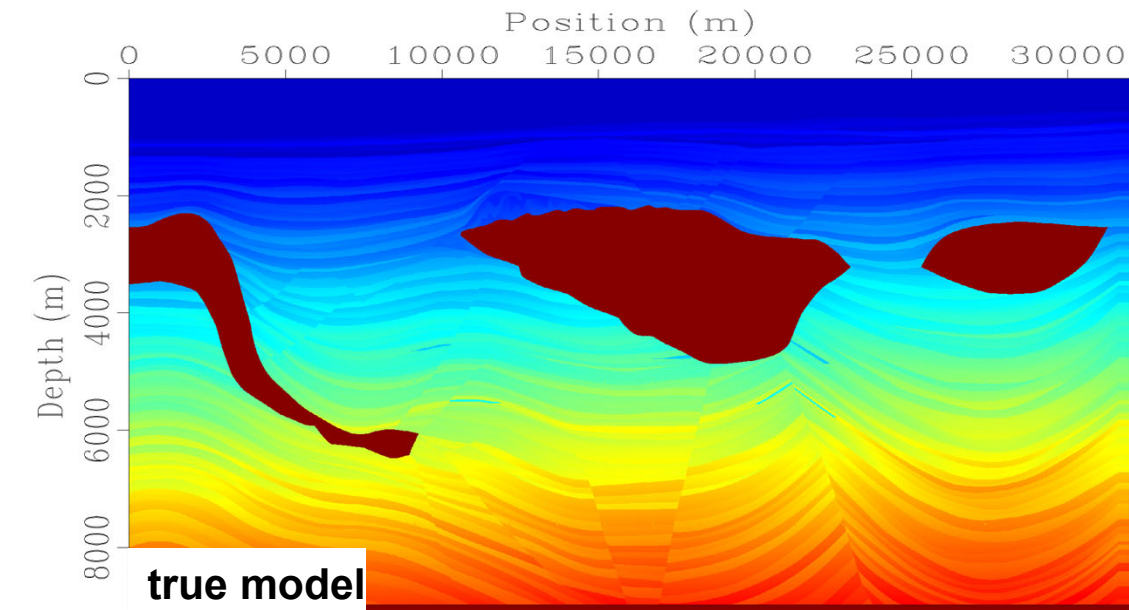
GeometryClass(2files,grid):
calculates necessary
information from x,y,z
All modules use the same
class to access geometry



Output from SEGY, line of shots + header files

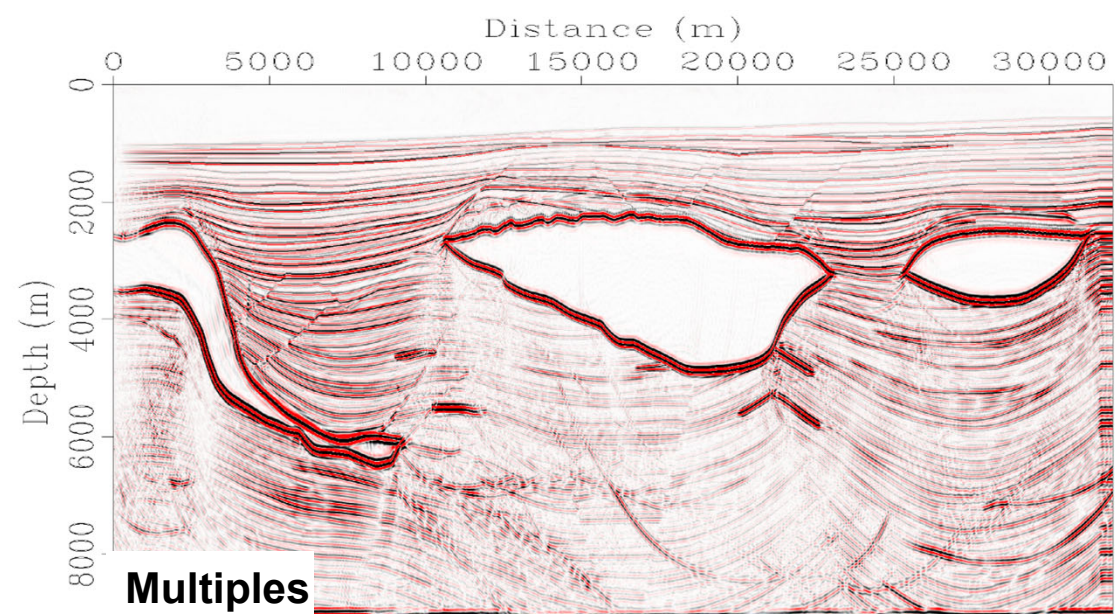
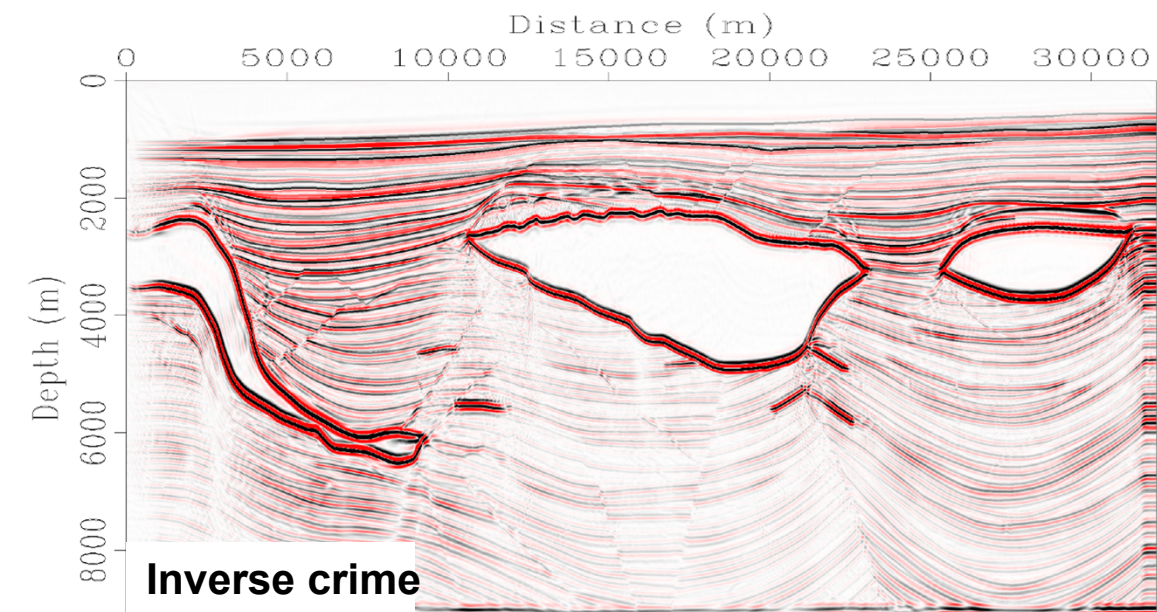
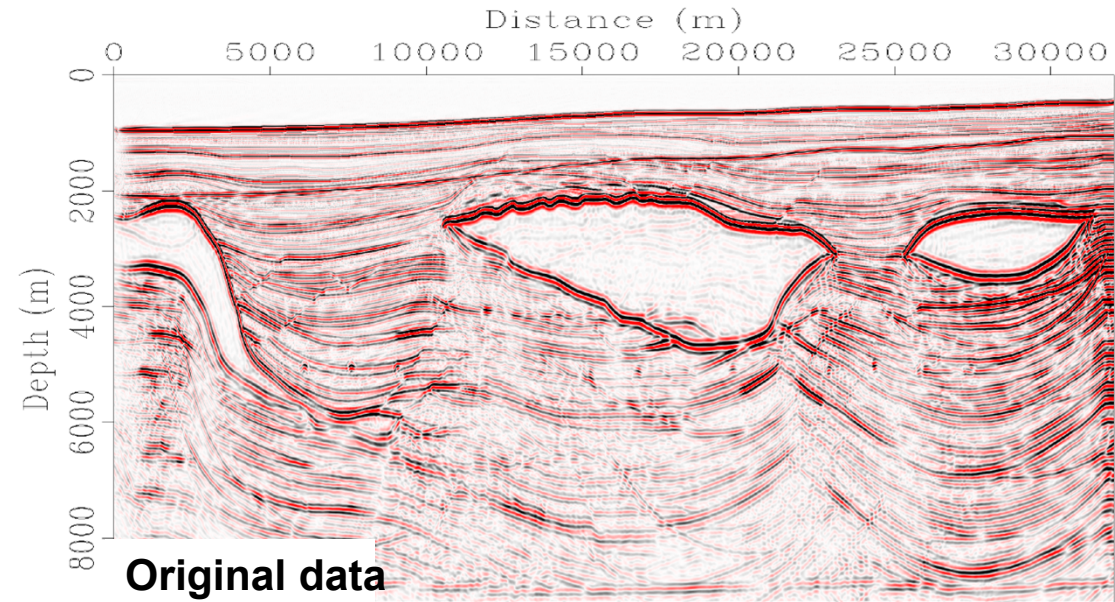
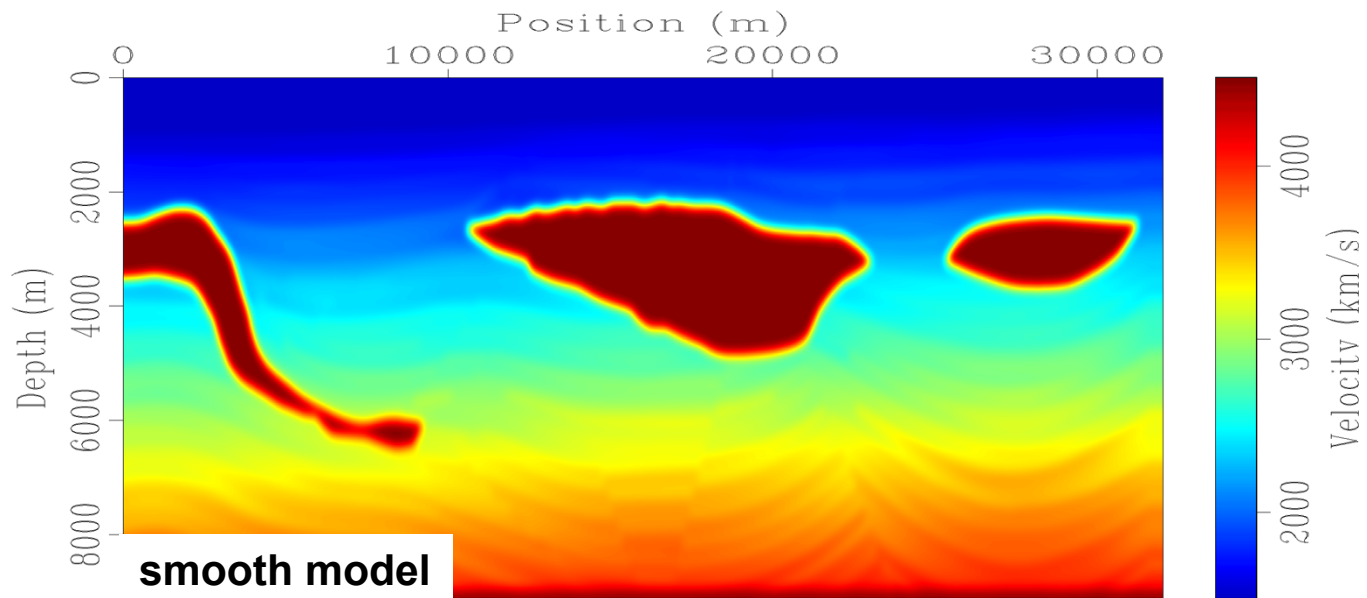


One shot from SEGY vs Synthetic





Realistic RTM tests in salt vs inverse crime

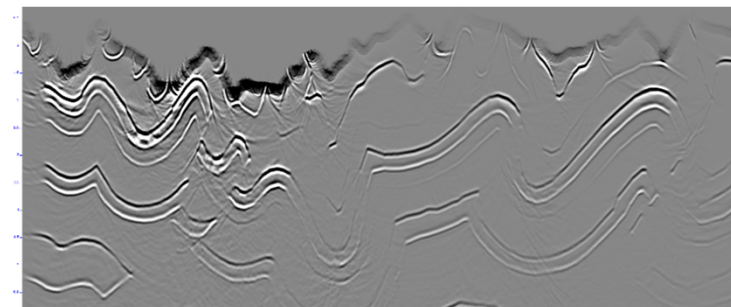
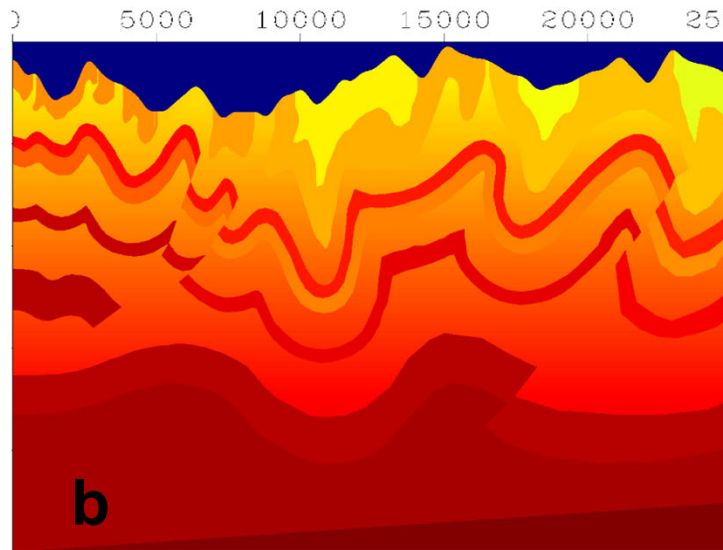
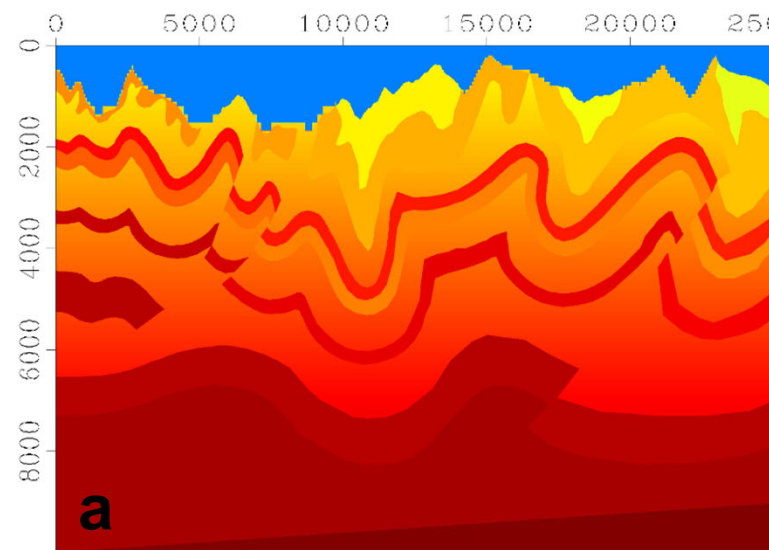




Foothills environment Modeling from topography: acoustic and elastic



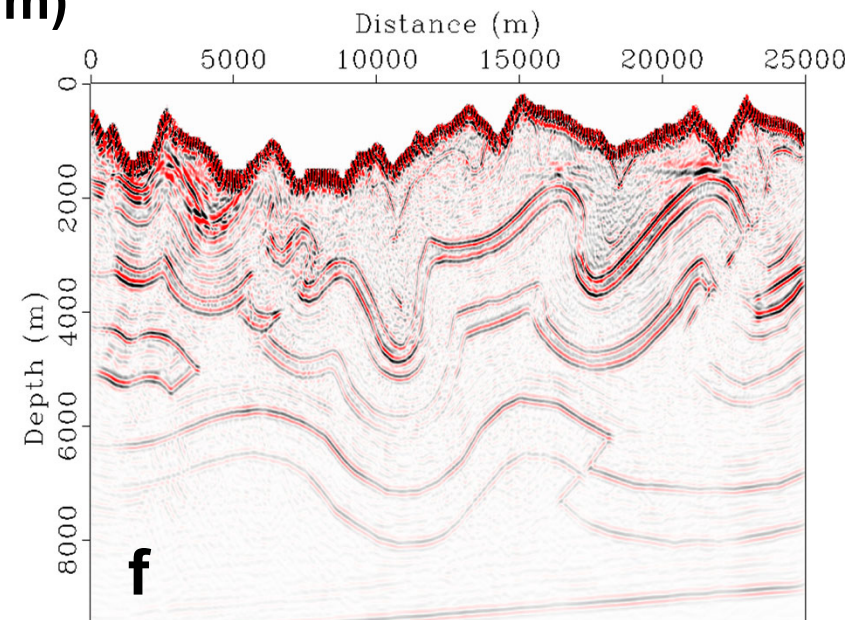
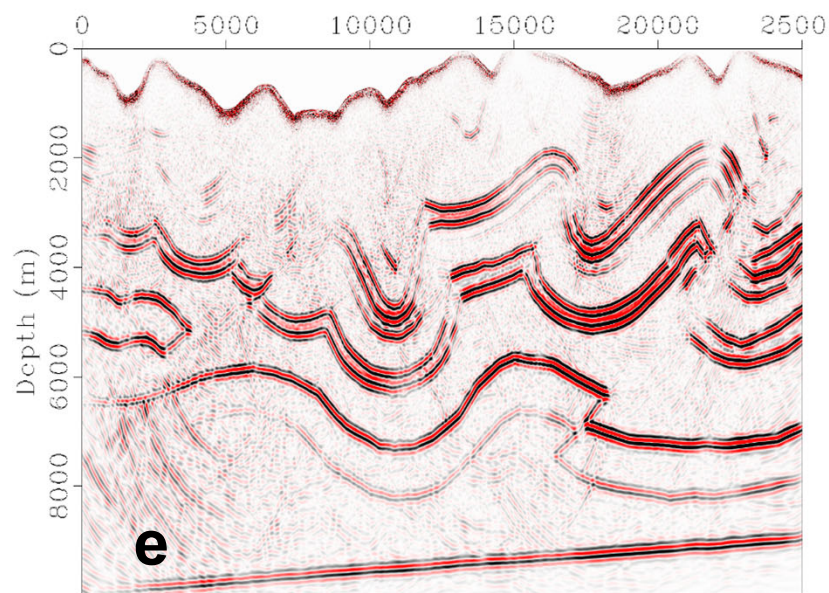
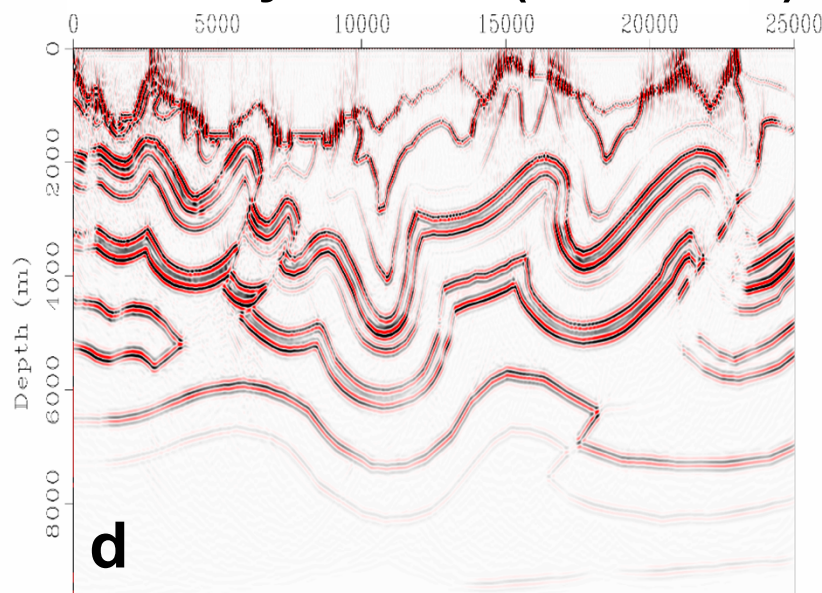
Foothills Example: acoustic from topography



**c – Kirchhoff Depth Migration
(from true data and topography)**

Velocity flooded (flat datum)

Velocity True (smooth datum)



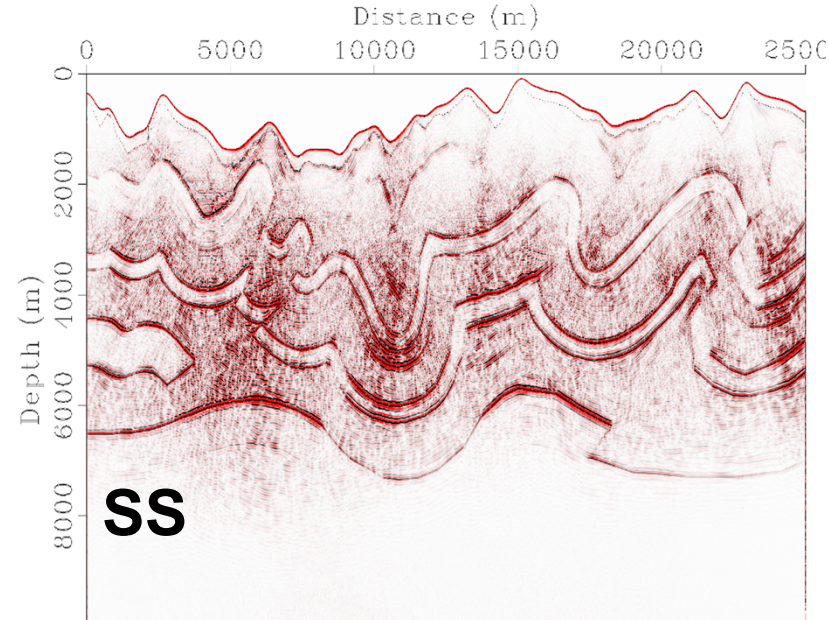
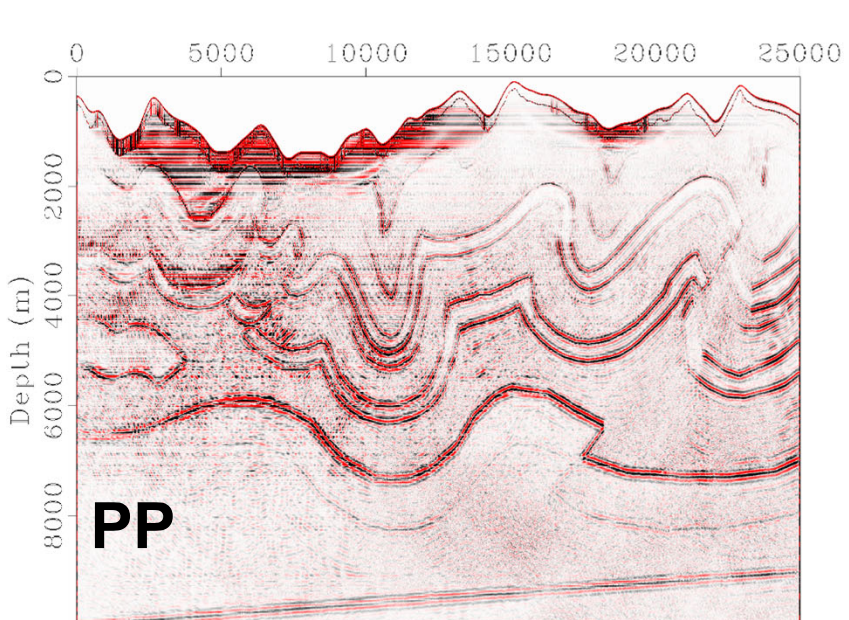
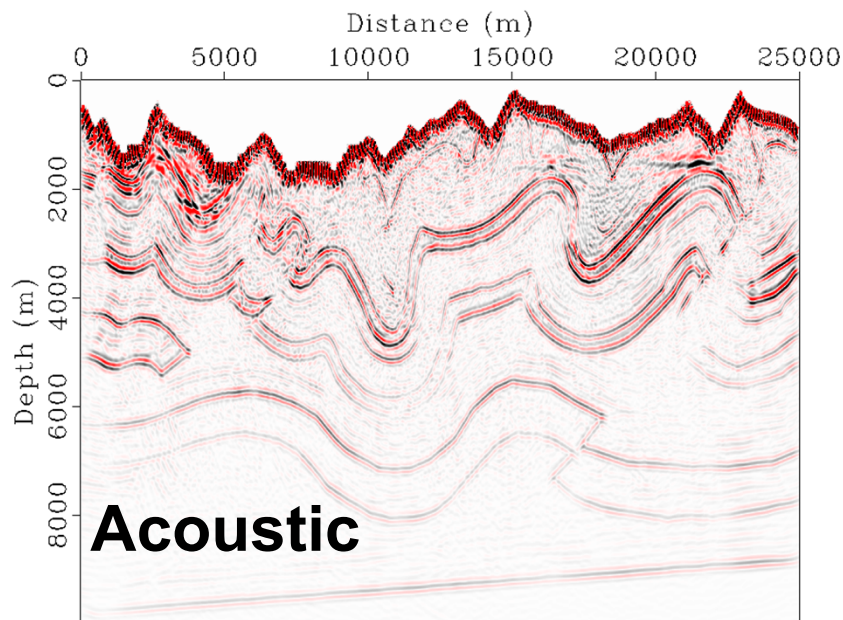
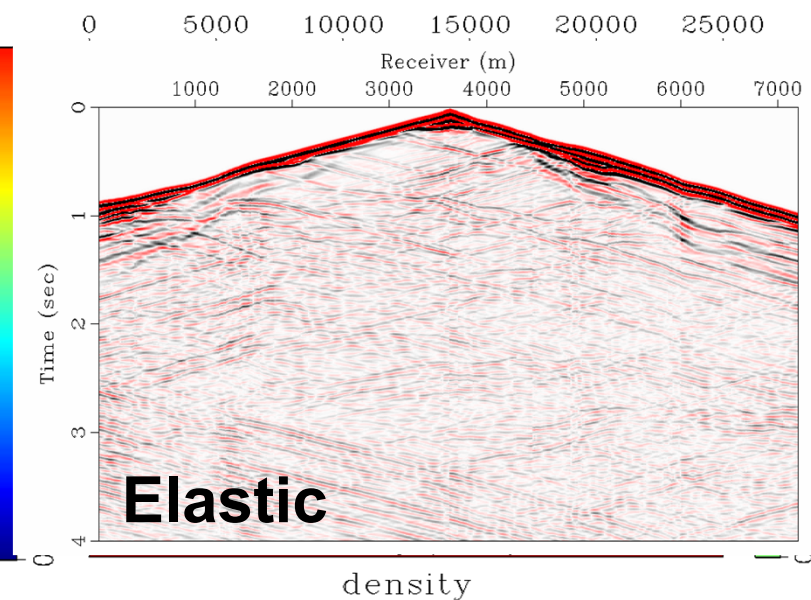
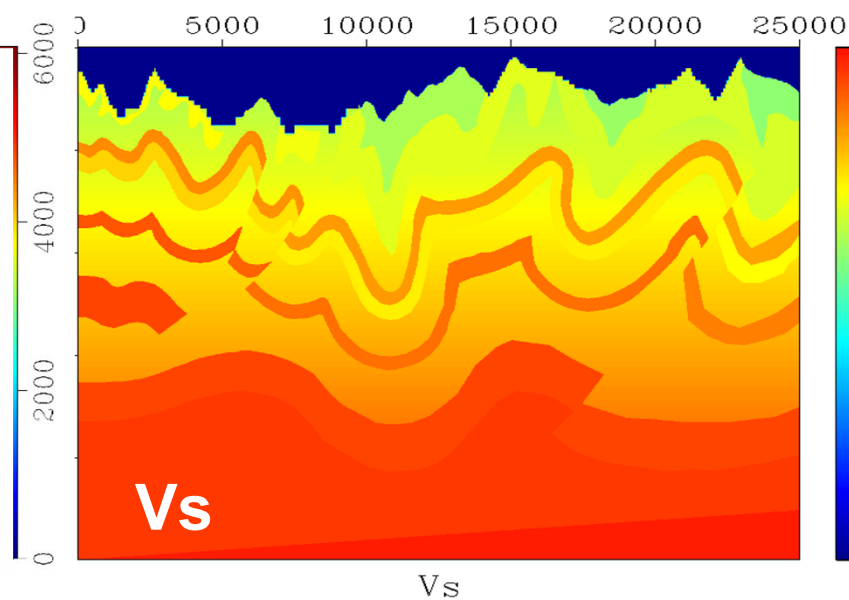
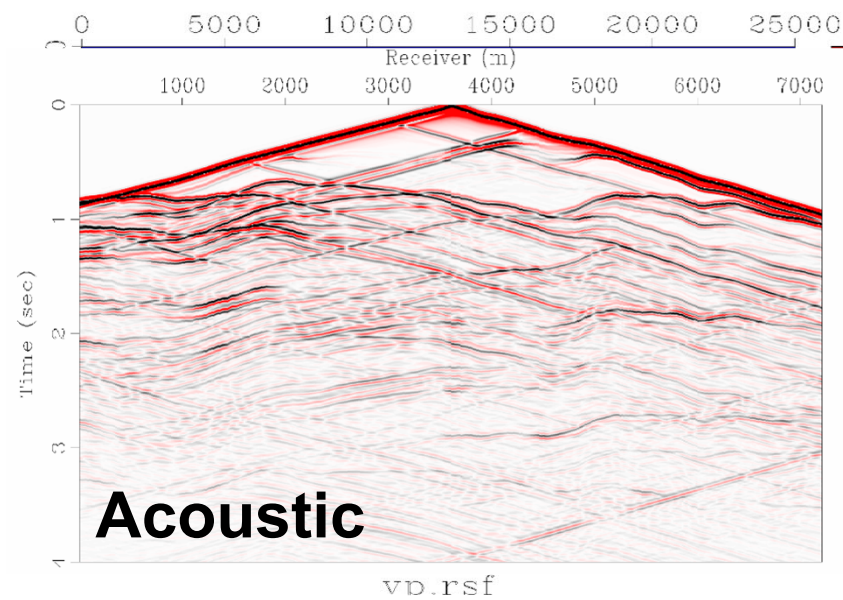
RTM synthetic geom from datum

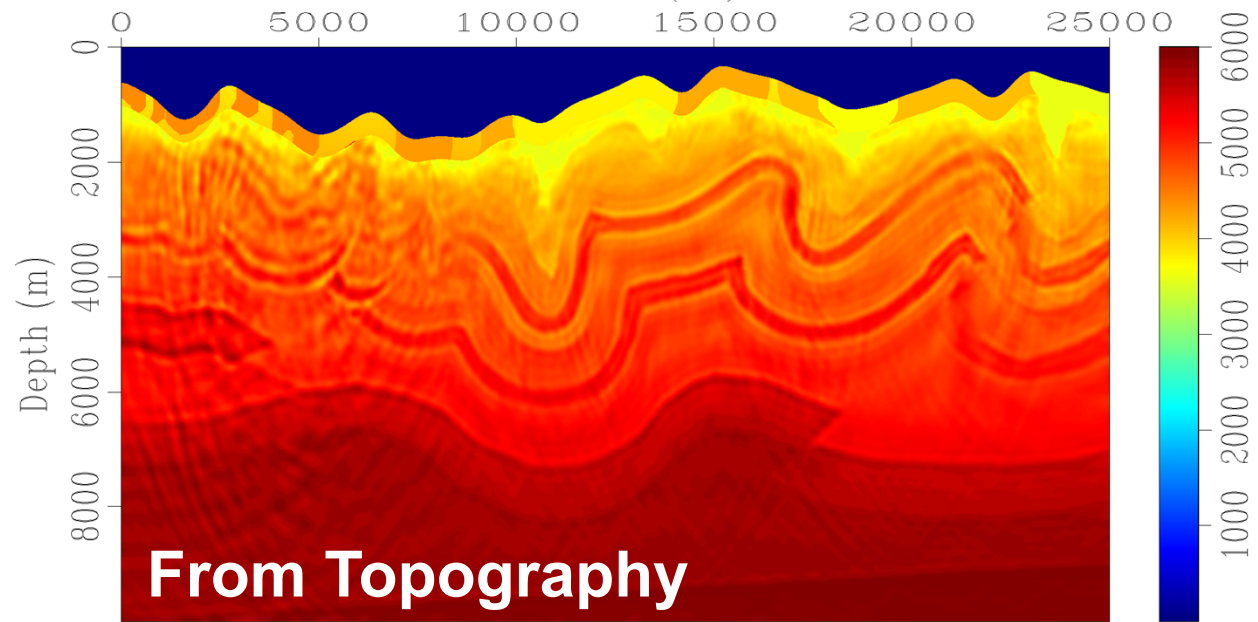
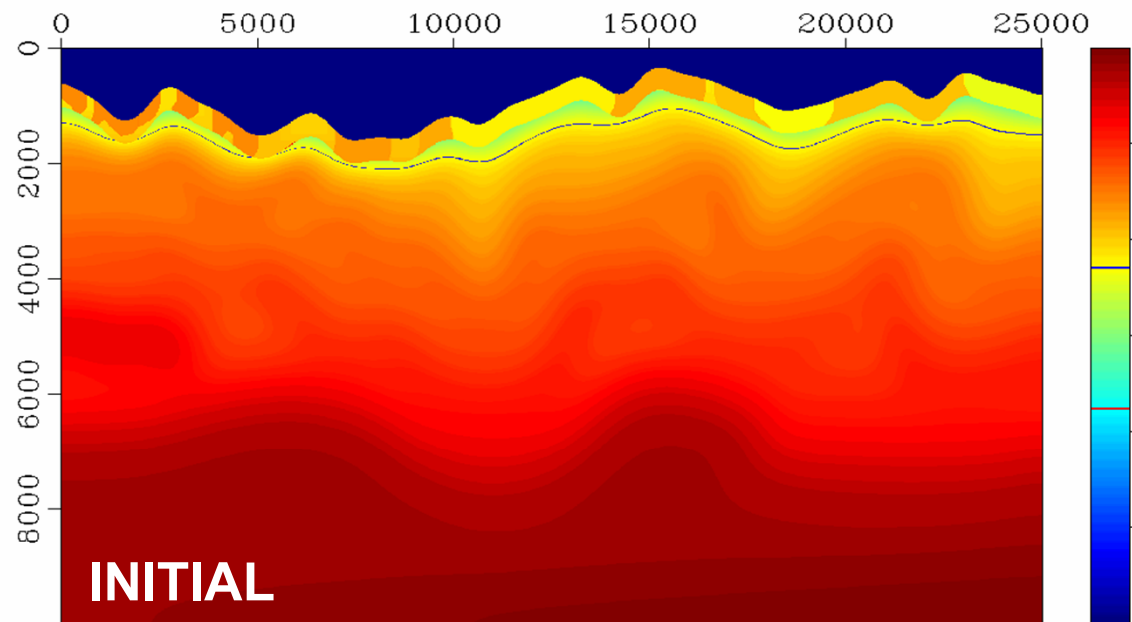
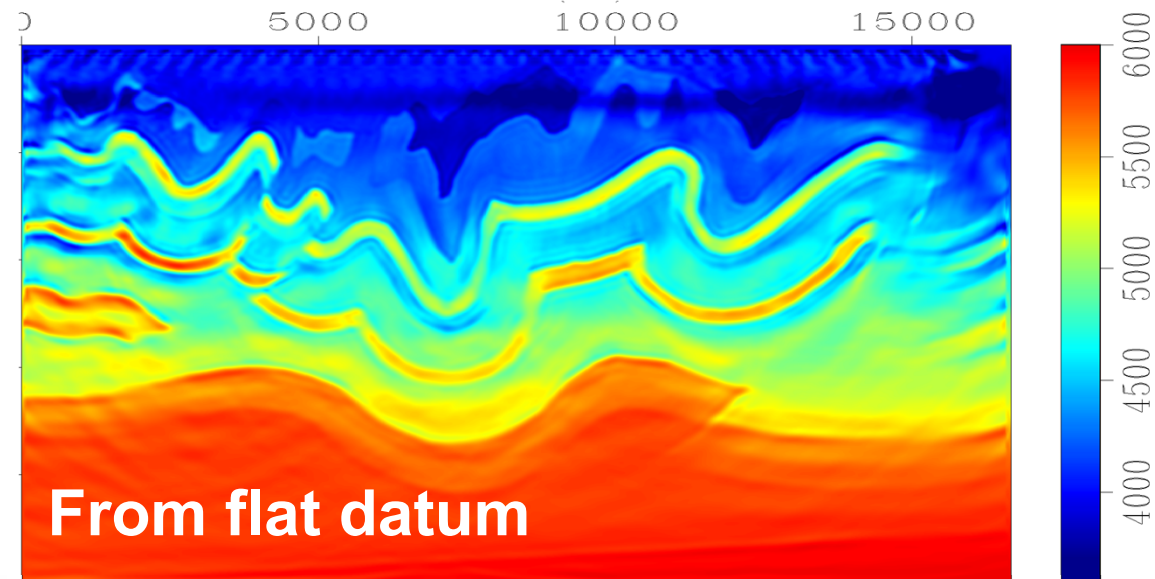
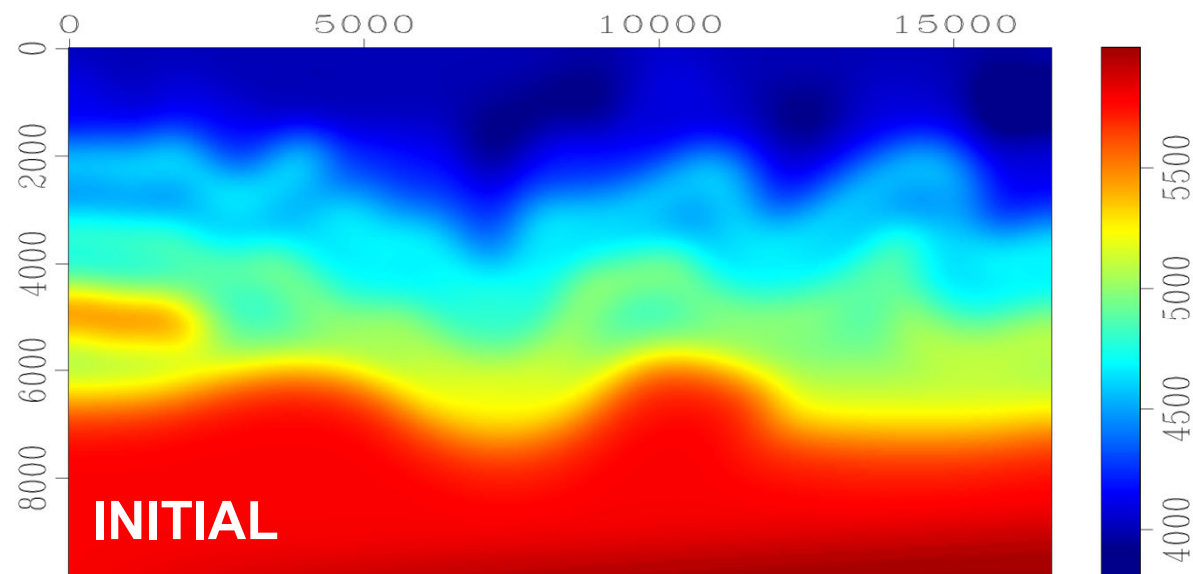
RTM synthetic from topography

RTM true data from topography



Foothills model (with near surface noise)



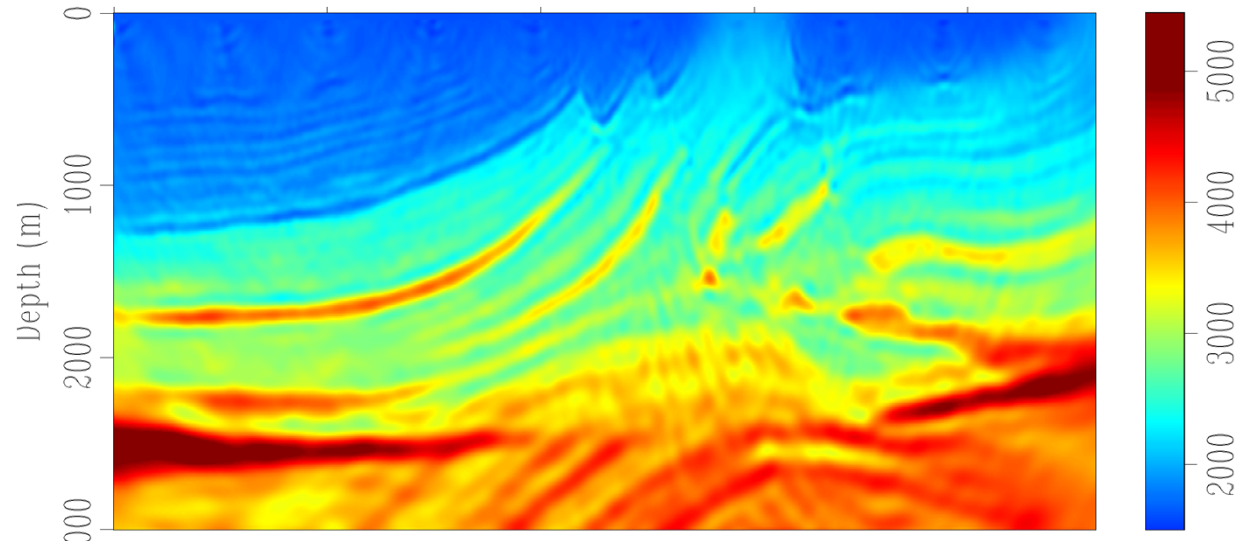
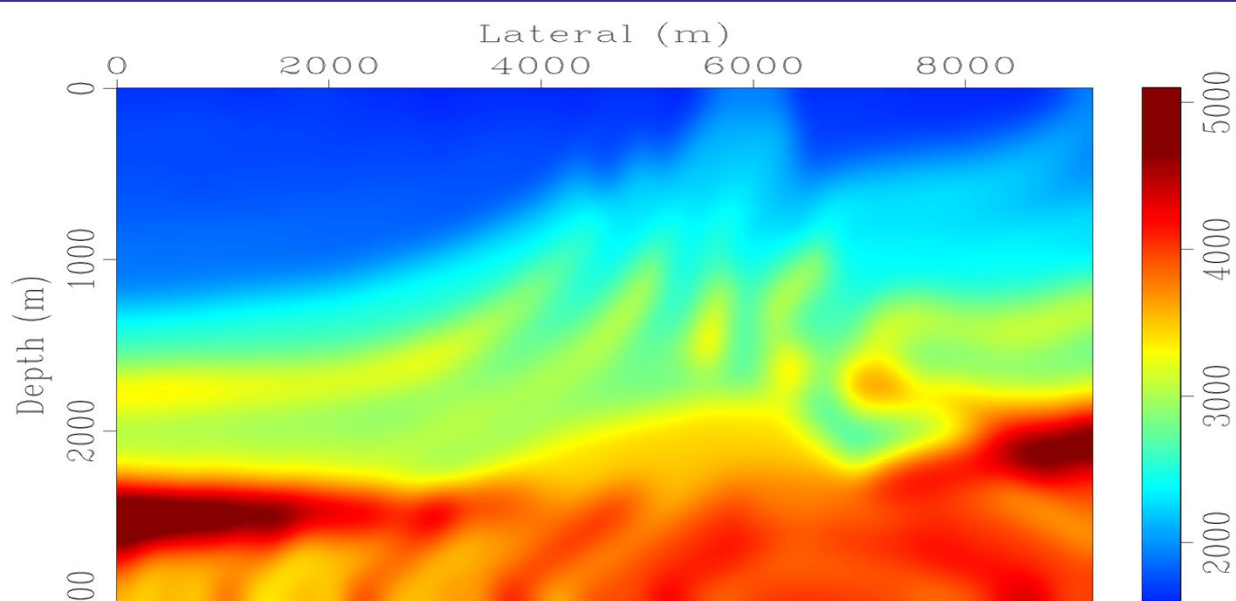


velinit.rsfsf

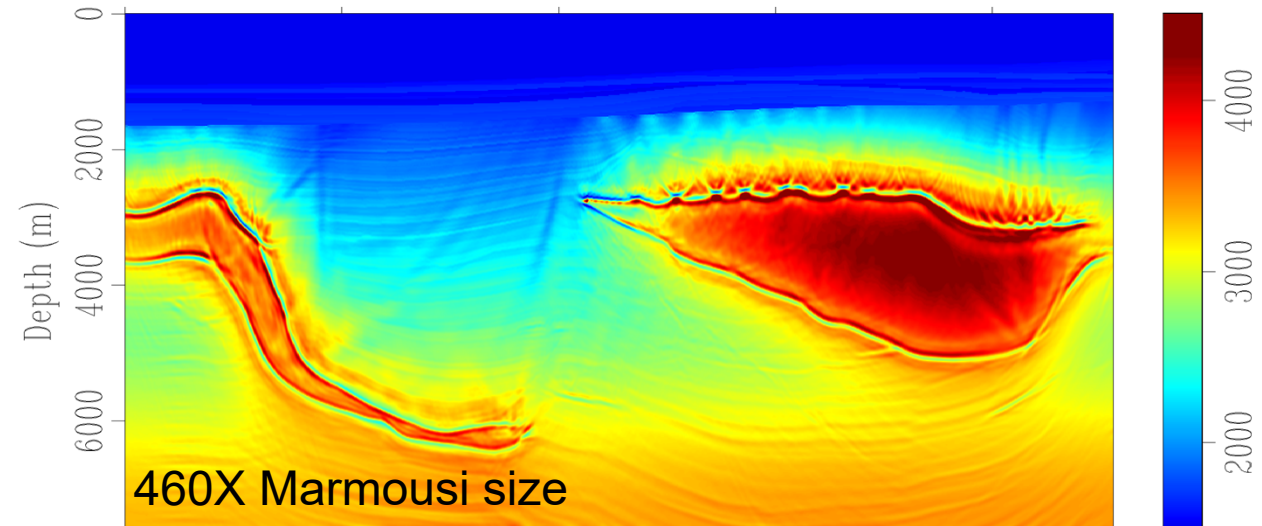
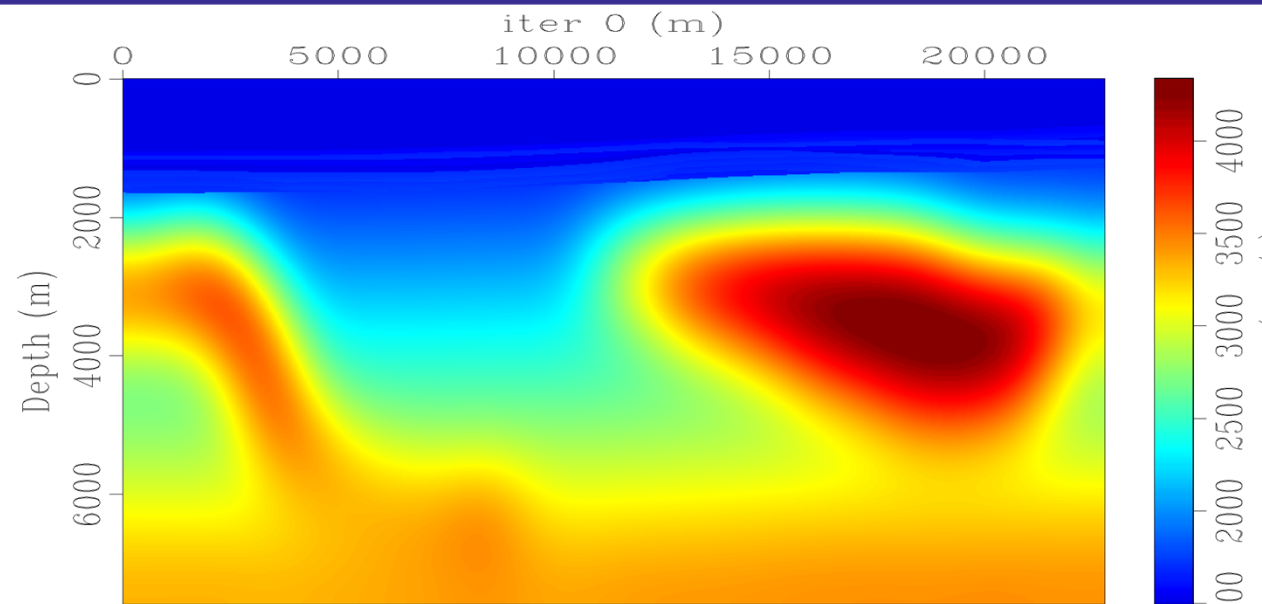
vsnap.rsfsf



The importance of size and dataflows



10 shots, 10 iterations, size=376x1151 nt=3600
2minutes 13 seconds in a GPU4060 (\$500)



300 shots, 20 iterations, nt=16000, 460X Marmousi
10 hours in a GP-A100 (\$5000)

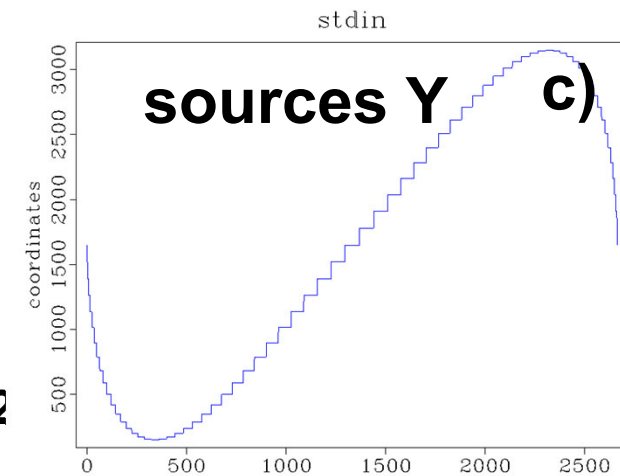
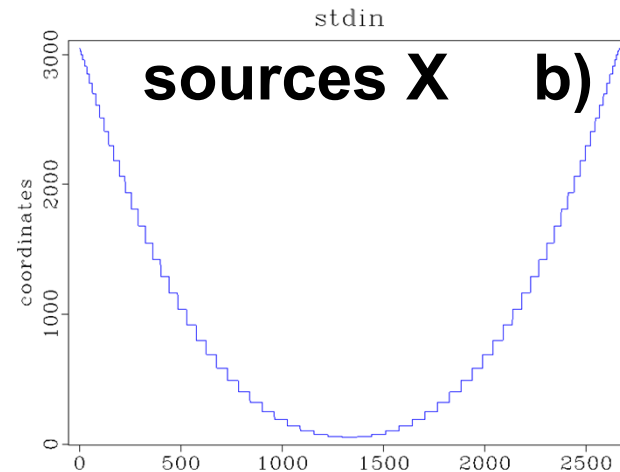
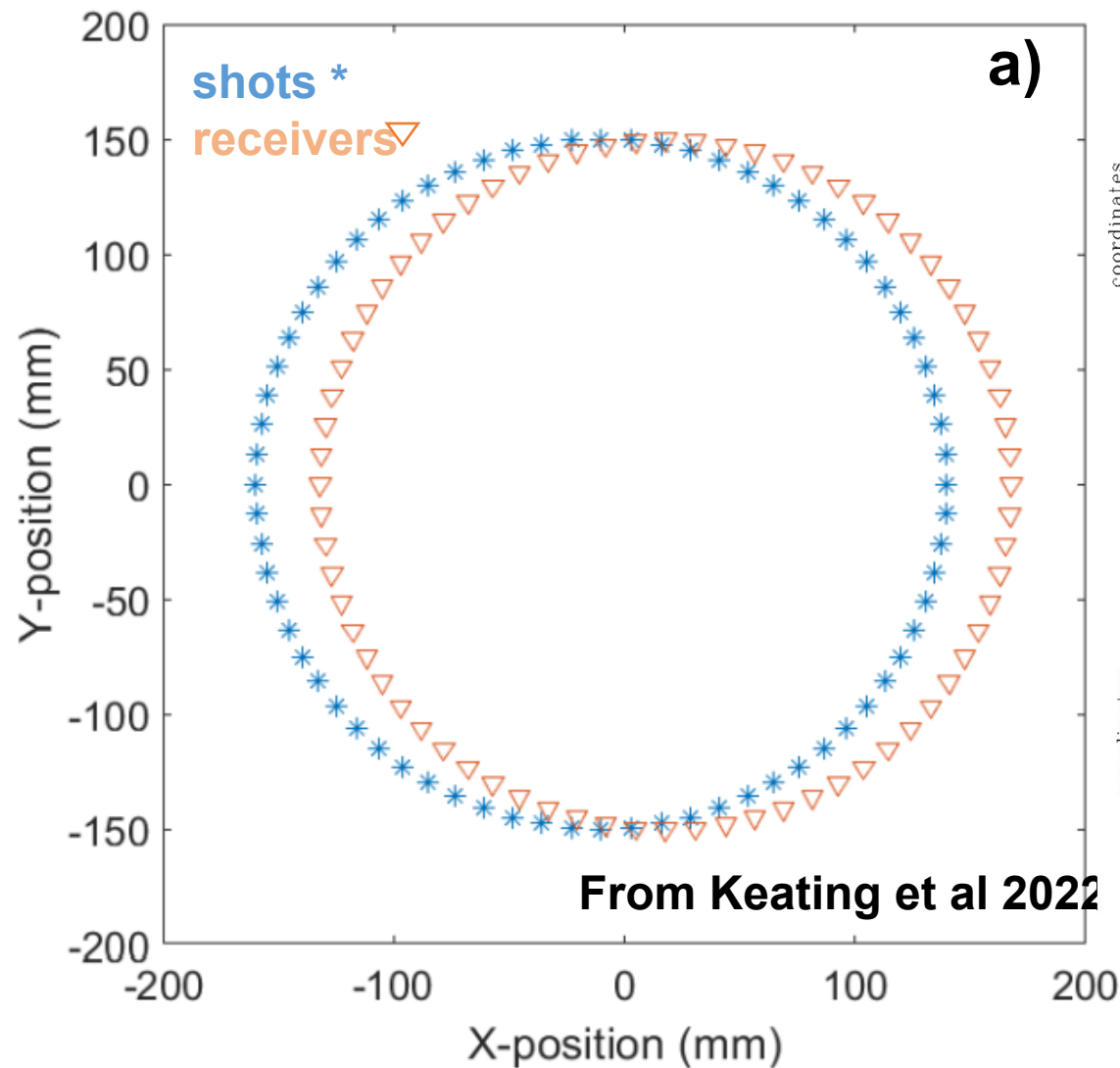


Physical modeling: How inverse crime can be useful



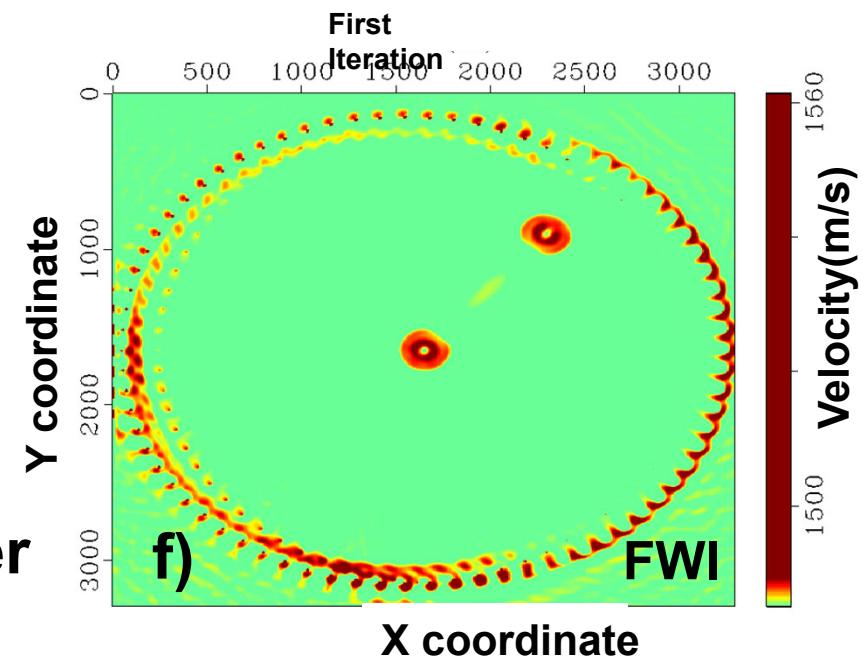
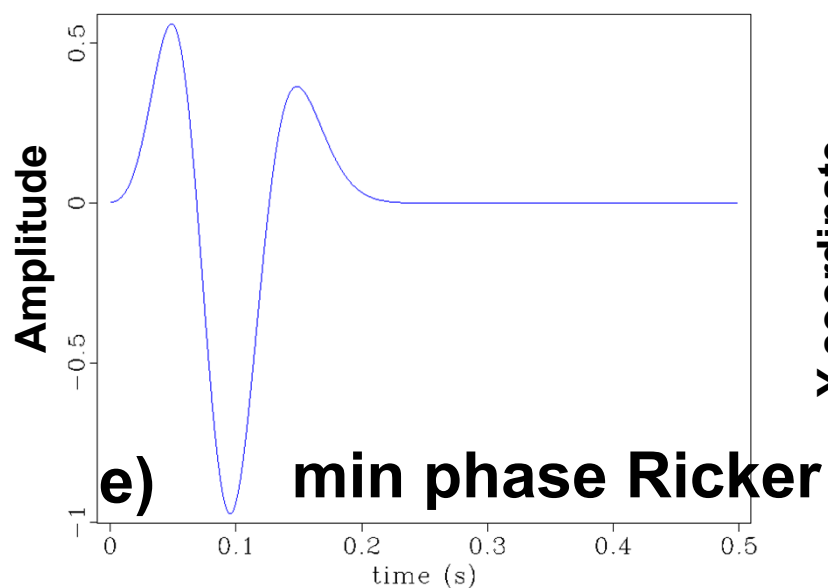
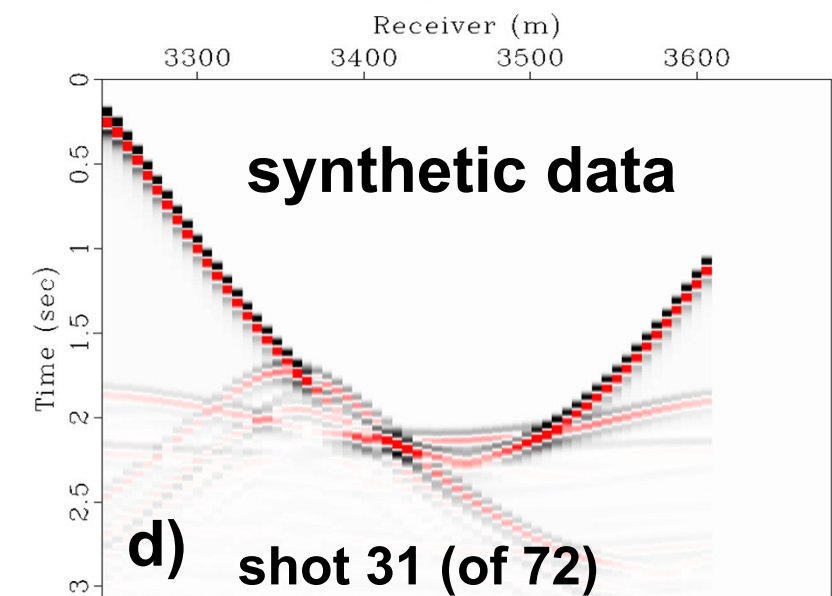
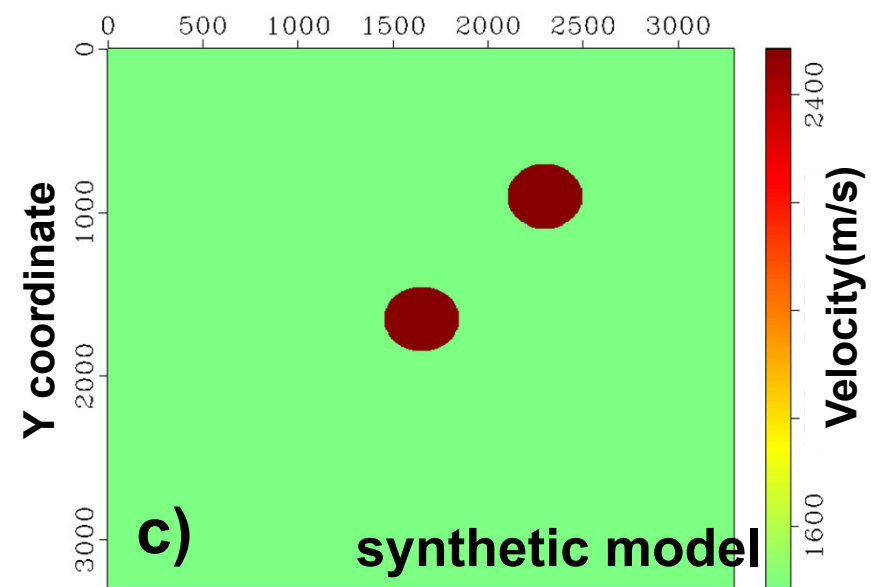
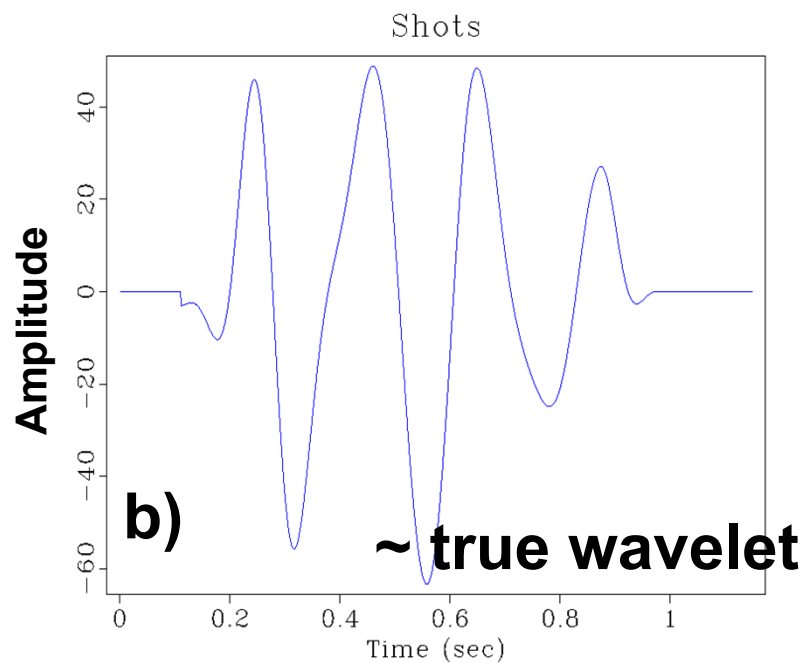
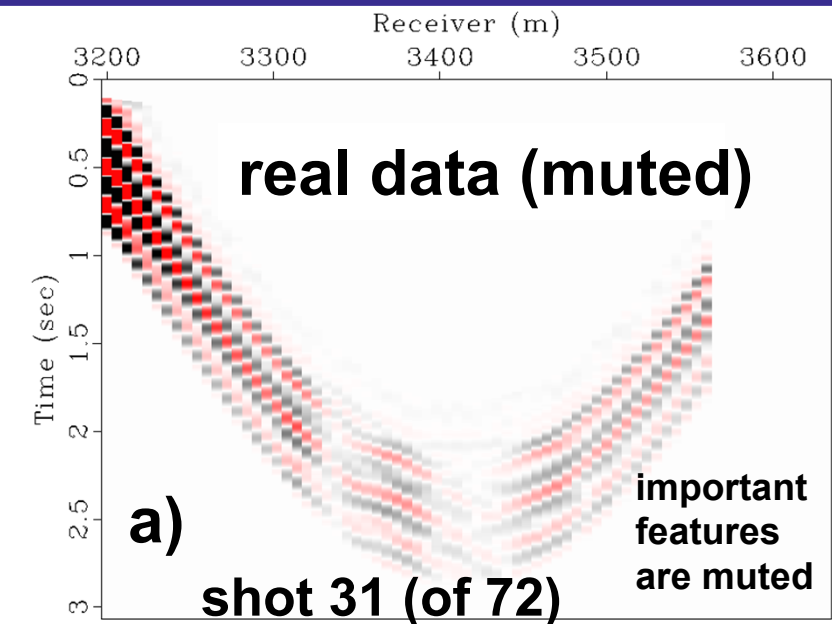
Physical experiment

Physical data created by Joe Wong, Kevin Bertram and Kevin Hall



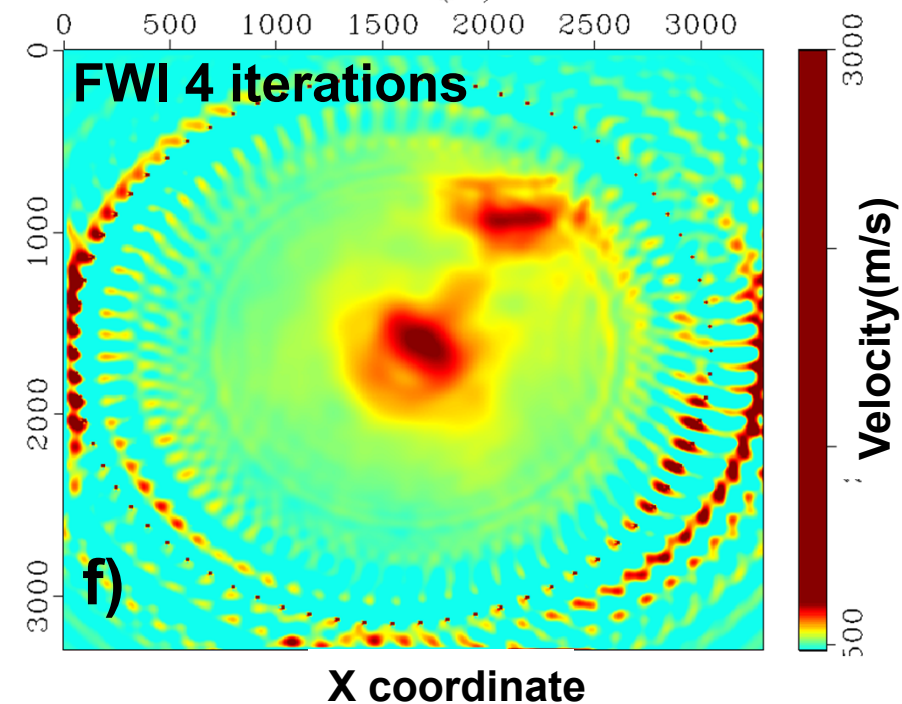
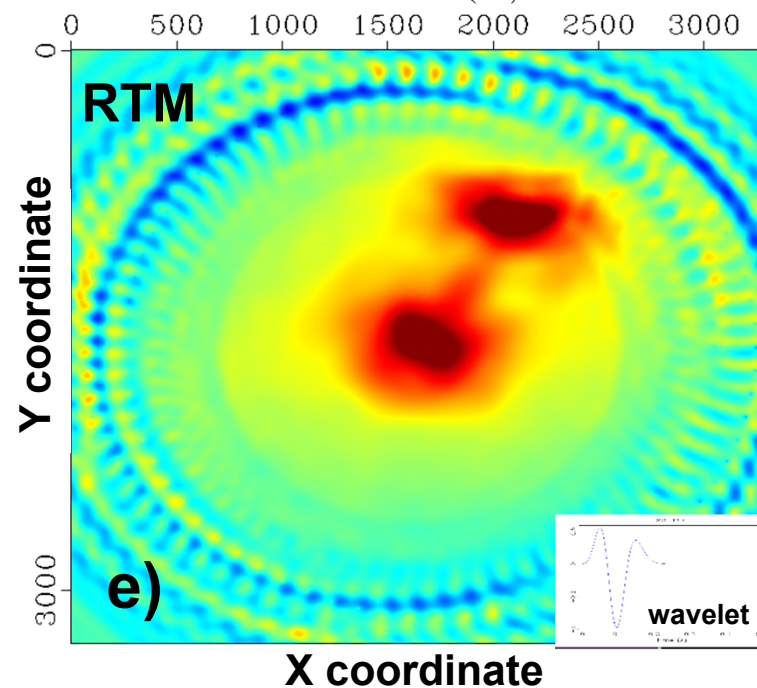
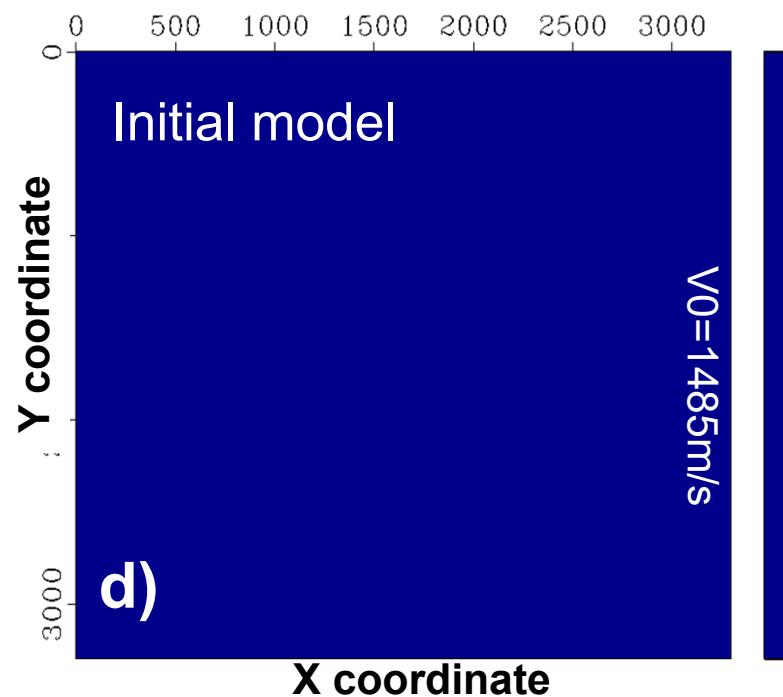
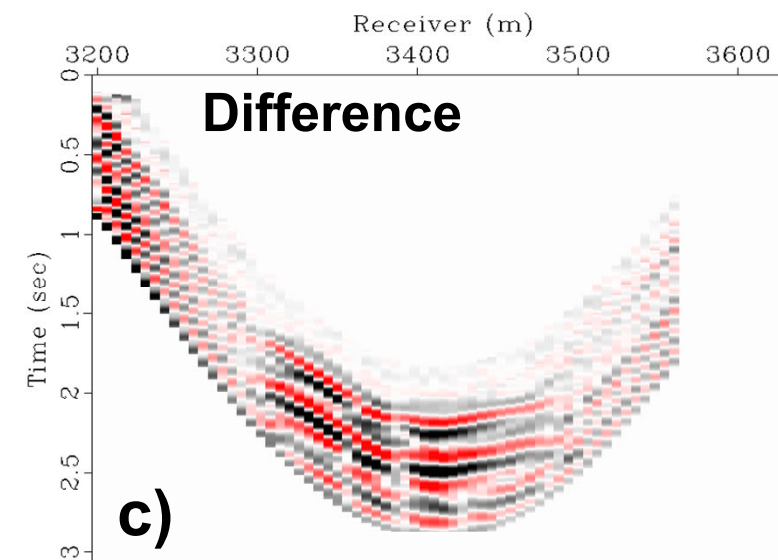
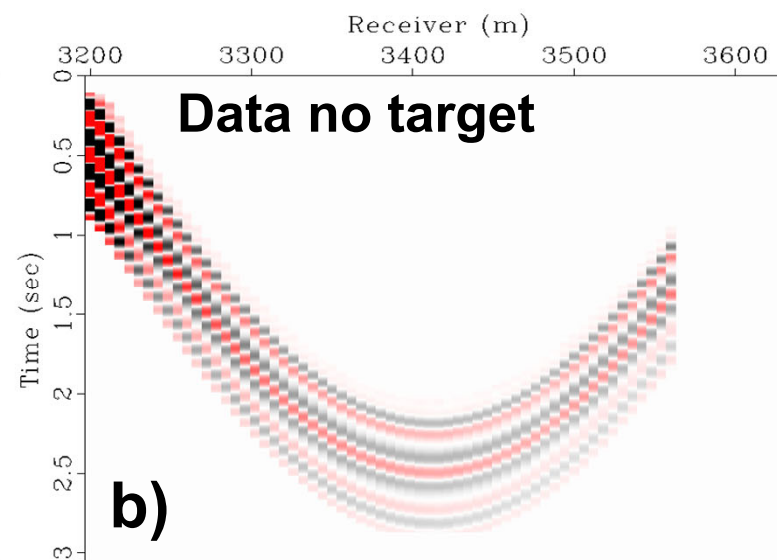
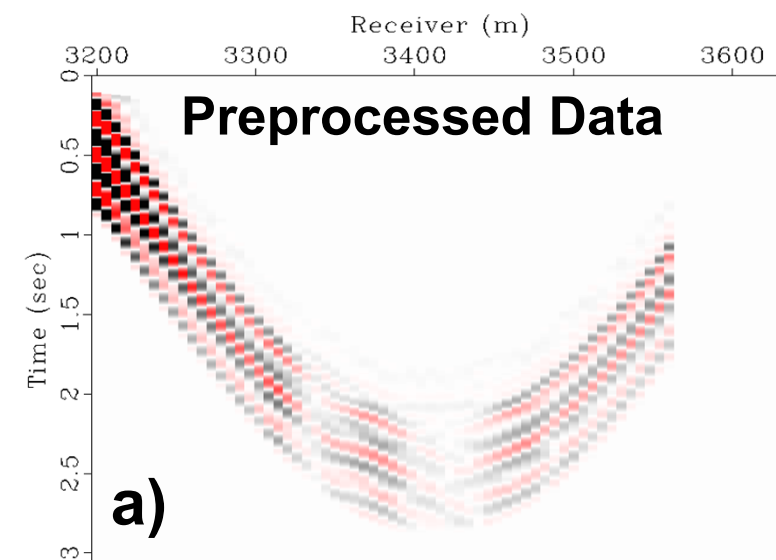


Real and synthetic data (same real geometry)





RTM from differences between target and no target (Real Data)



Present and Future work 3D



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3D modelling

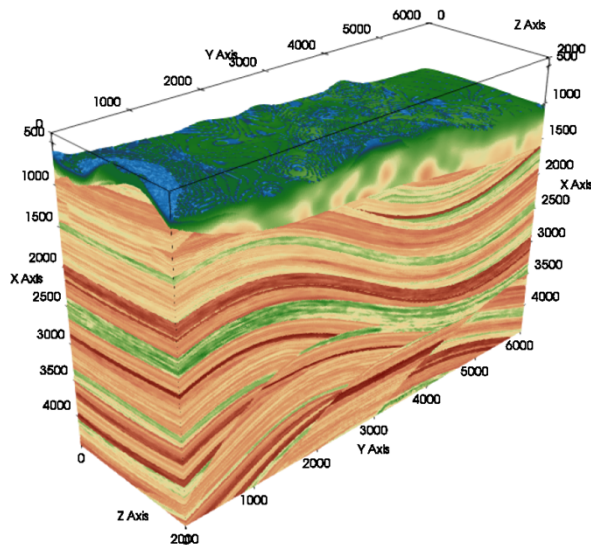
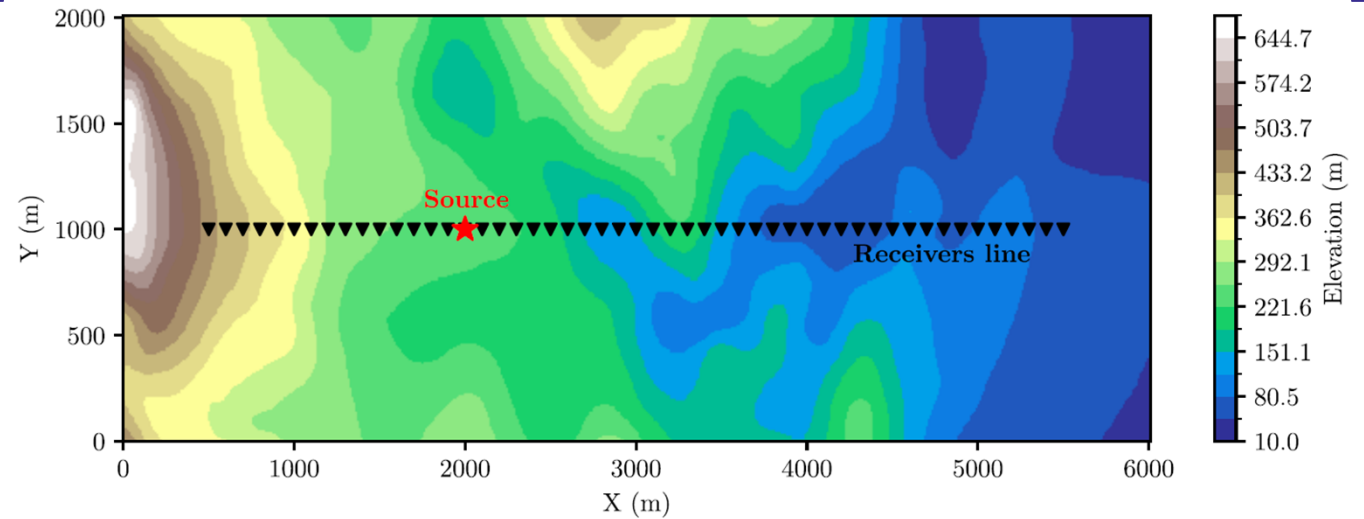
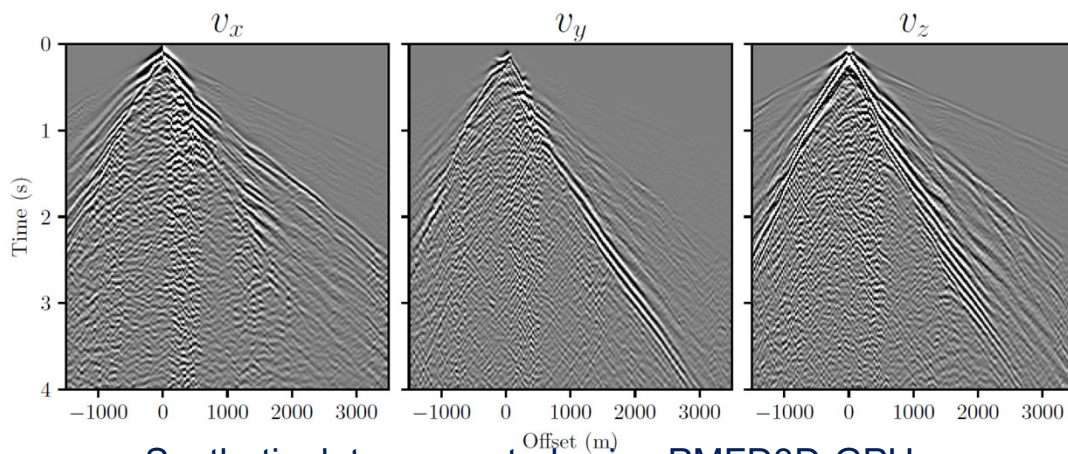


Figure 11. Portion of SEAM Foothills Model.



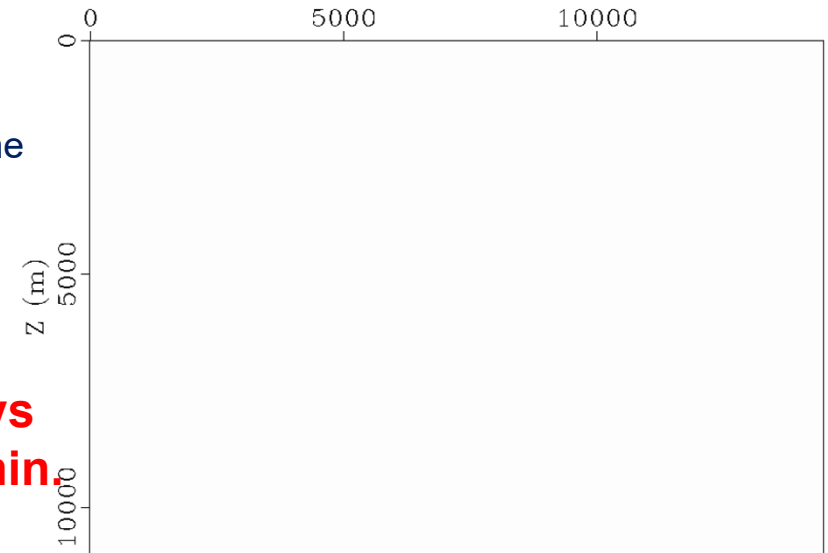
Elevation map and acquisition geometry from the portion of SEAM model.



Synthetic data generated using PMFD3D-GPU.

Simulation of the
wave propagation.

CPU (Matlab): 2.6 days
GPU (CUDA-C): 7.5 min.



Numerical example SEAM model



Long term project to increase the realism of testing seismic algorithms

Adapted dataflow and created modules to work with real data and real geometries.

Compared inverse crime scenarios with real scenarios for QC and baselines

Adapted dataflow to handle large volumes of data and large computations (HPC)

Applied to many scenarios, topography, salt, physical modelling and working on 3D.



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Modelling from topography (Ivan Sanchez)

$$D_t^- v_x = b_x (D_x^+ \sigma_{xx} + D_y^- \sigma_{xy} + D_z^- \sigma_{zx}),$$

$$D_t^- v_y = b_y (D_x^- \sigma_{xy} + D_y^+ \sigma_{yy} + D_z^- \sigma_{yz}),$$

$$D_t^- v_z = b_z (D_x^- \sigma_{zx} + D_y^- \sigma_{yz} + D_z^+ \sigma_{zz}),$$

$$D_t^+ \sigma_{xx} = (\lambda + 2\mu) D_x^- v_x + \lambda D_y^- v_y + \lambda D_z^- v_z,$$

$$D_t^+ \sigma_{yy} = \lambda D_x^- v_x + (\lambda + 2\mu) D_y^- v_y + \lambda D_z^- v_z,$$

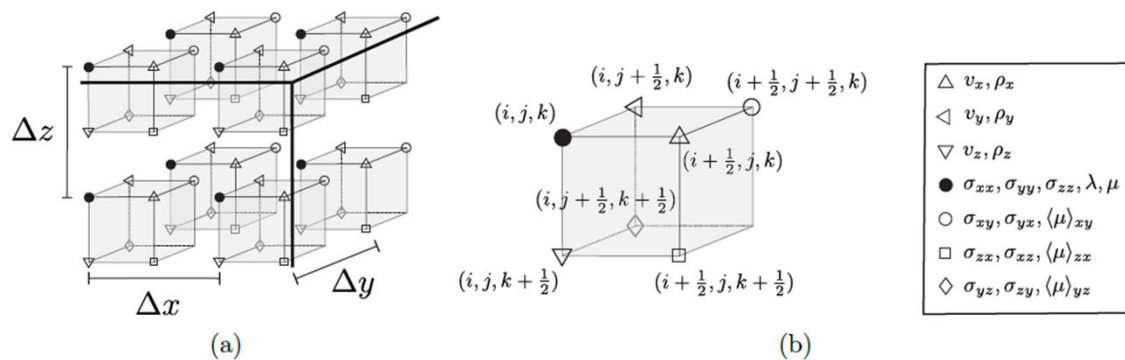
$$D_t^+ \sigma_{zz} = \lambda D_x^- v_x + \lambda D_y^- v_y + (\lambda + 2\mu) D_z^- v_z,$$

$$D_t^+ \sigma_{xy} = \langle \mu \rangle_{xy} (D_x^+ v_y + D_y^+ v_x),$$

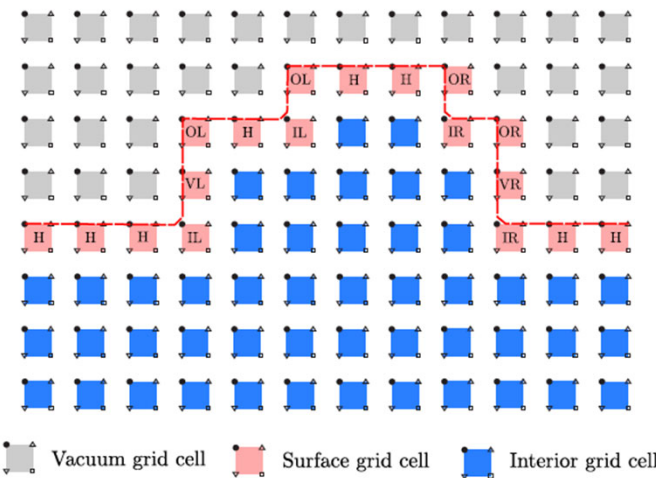
$$D_t^+ \sigma_{yz} = \langle \mu \rangle_{xy} (D_y^+ v_z + D_z^+ v_y),$$

$$D_t^+ \sigma_{zx} = \langle \mu \rangle_{xy} (D_z^+ v_x + D_x^+ v_z),$$

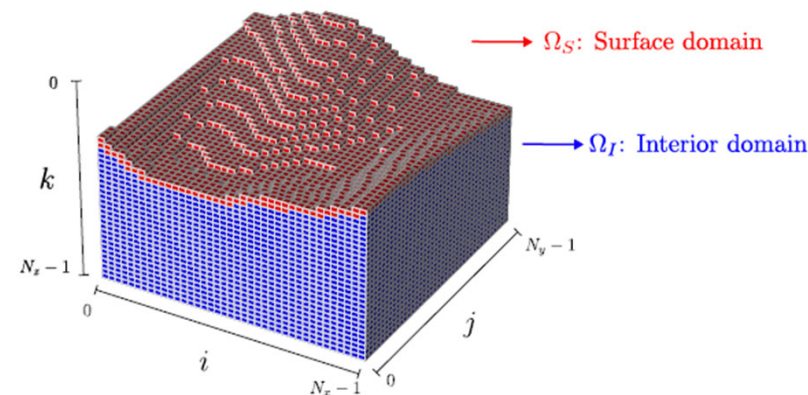
Elastic wave equation with velocity-stress formulation.



Staggered grid scheme. (a) 3D grid. (b) 3D cell.



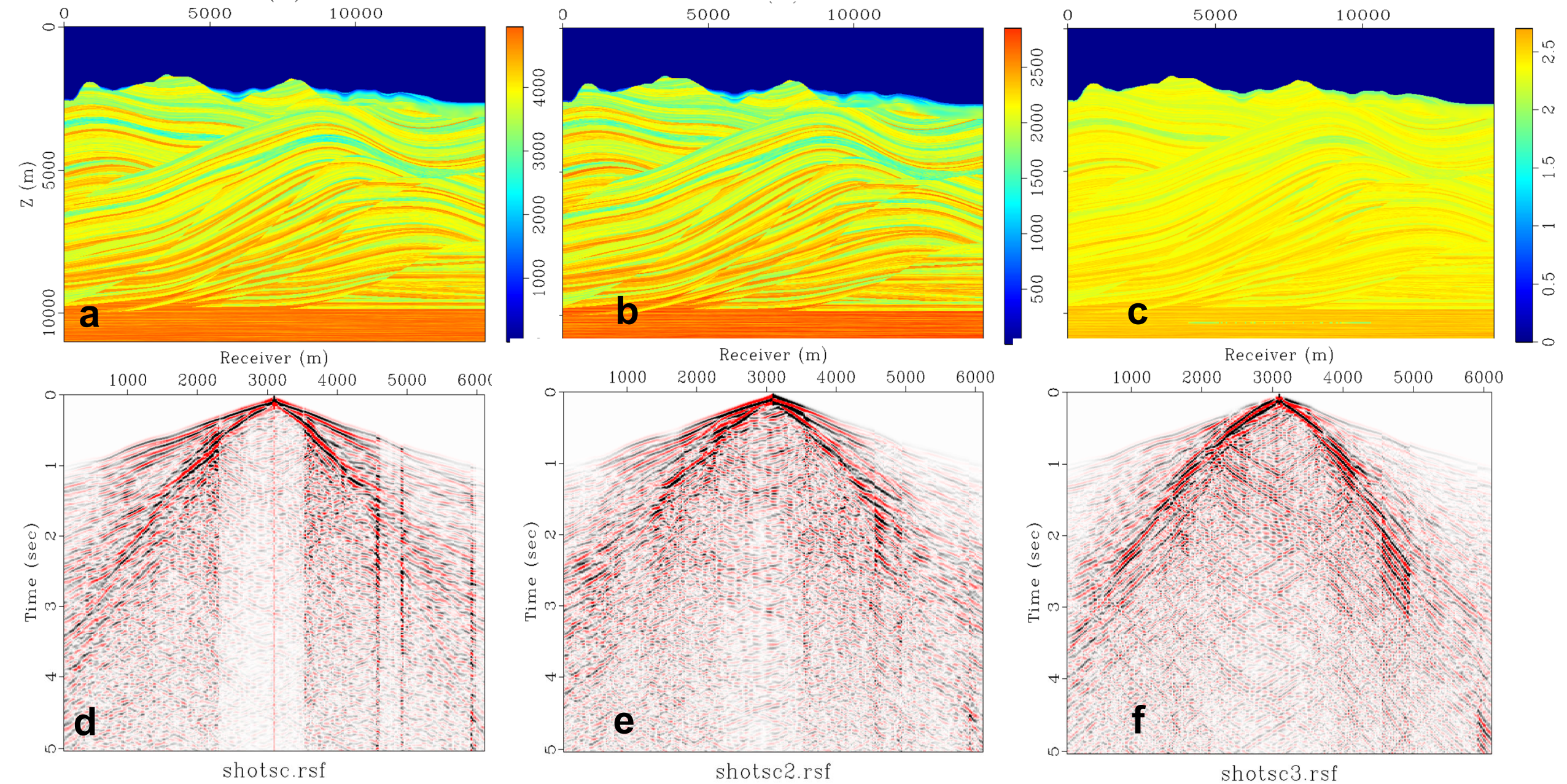
Grid cell classification. Parameter averaging in the surface cells is performed differently from interior ones.



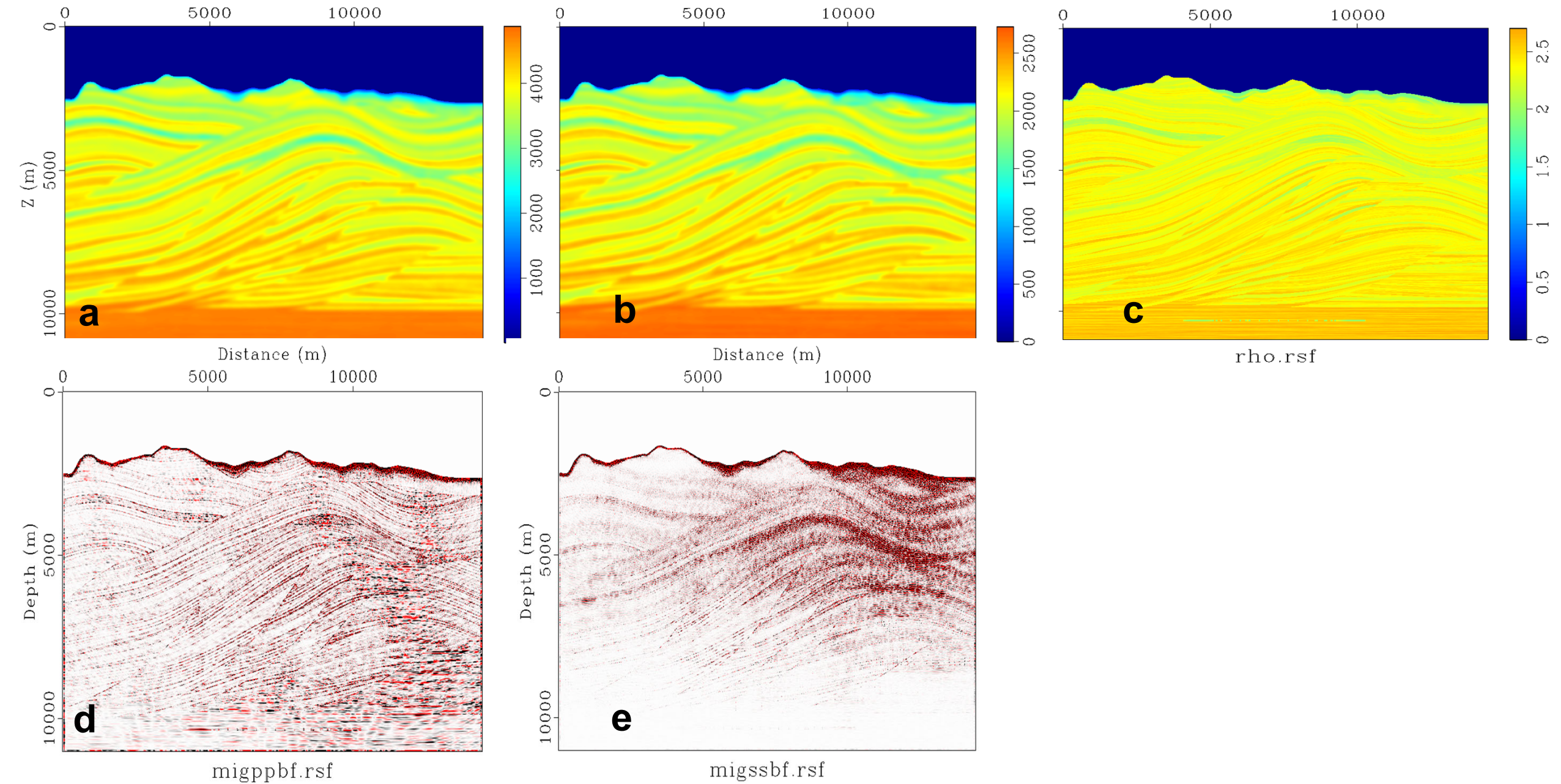
Domain decomposition strategy. Independent CUDA-C kernels for surface and interior domain.

PMFD3D-GPU: Parameter modified finite difference solver

SEAM 2 Elastic from Topography



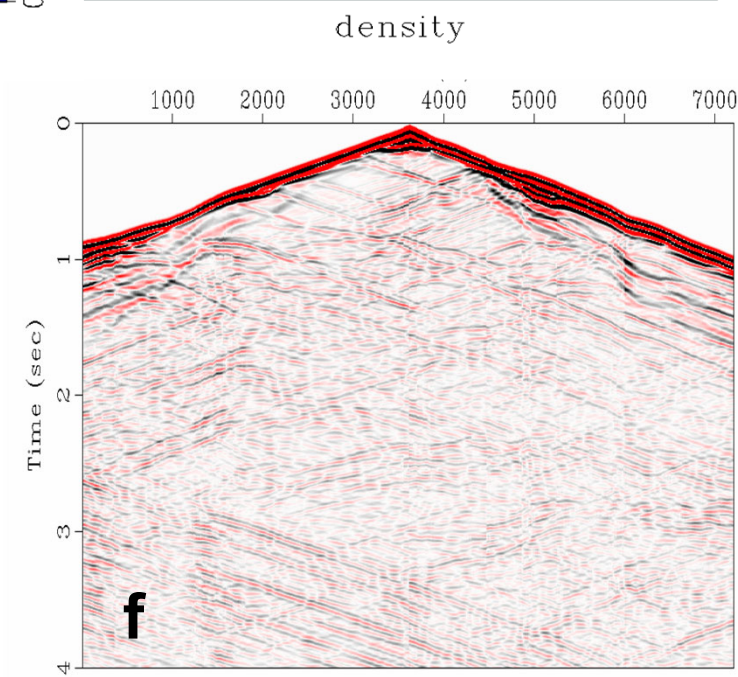
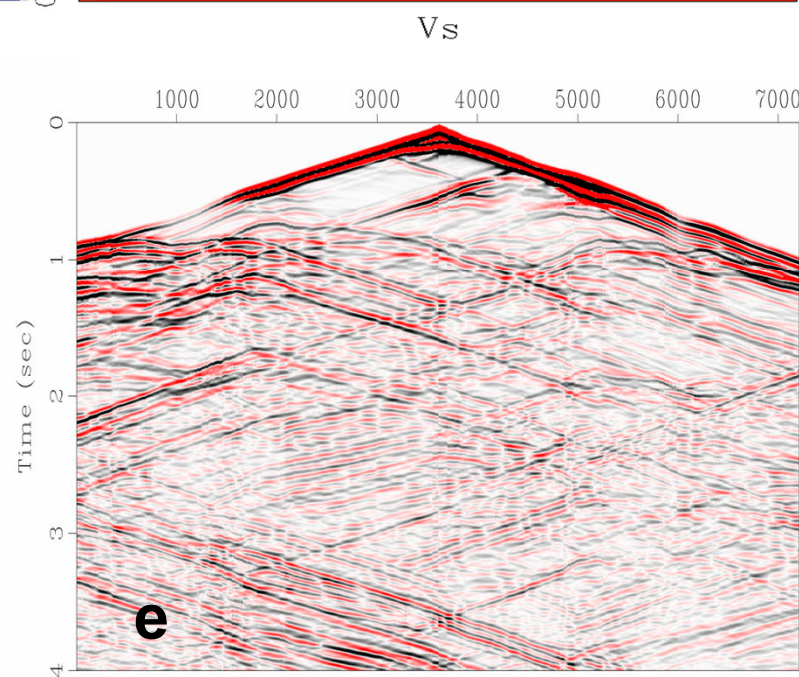
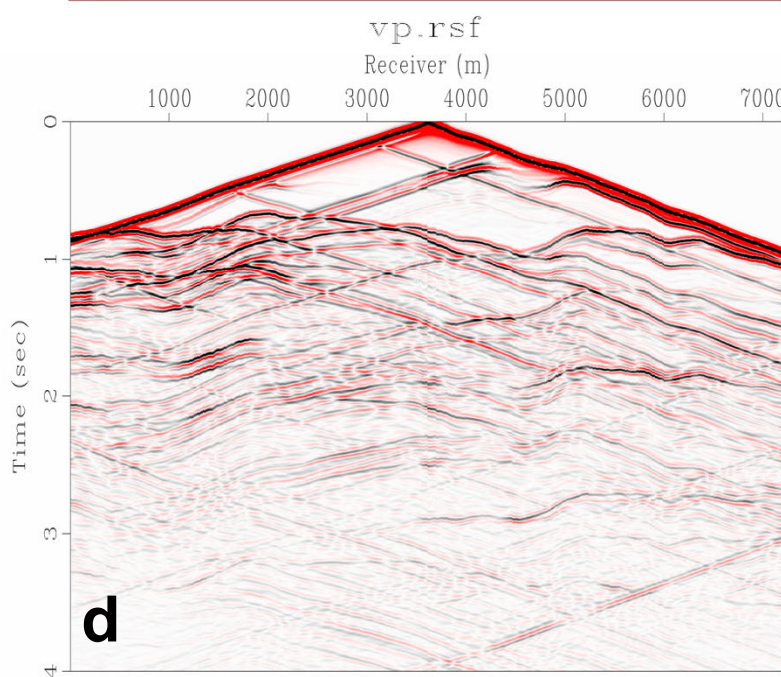
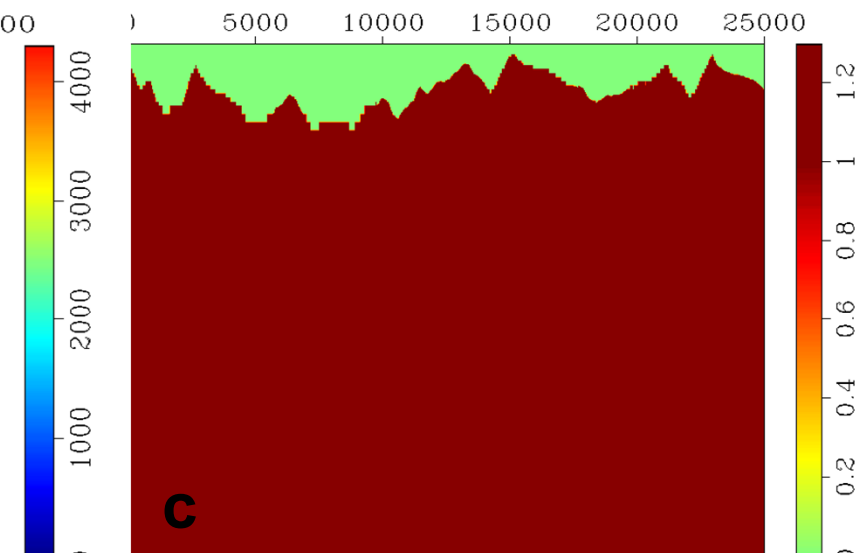
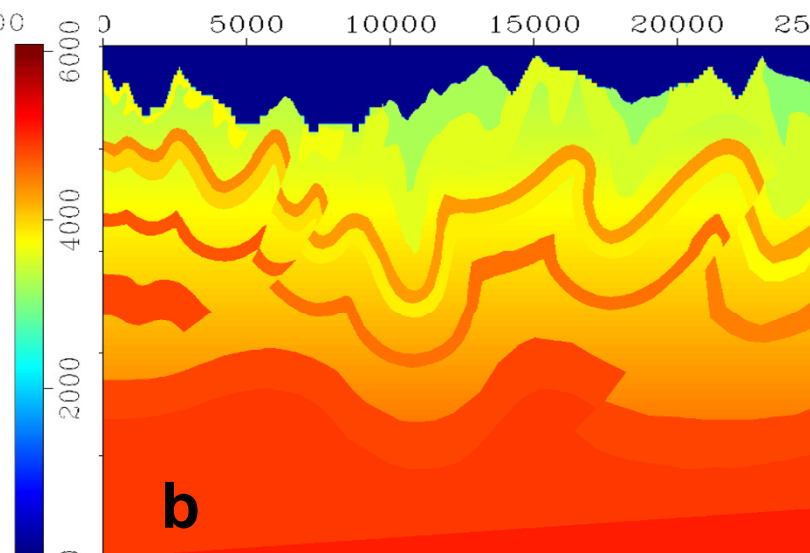
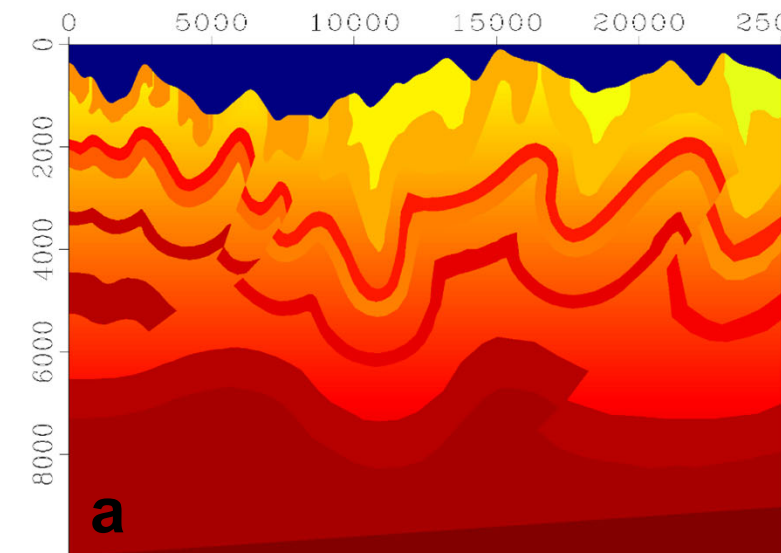
SEAM 2 Elastic from Topography

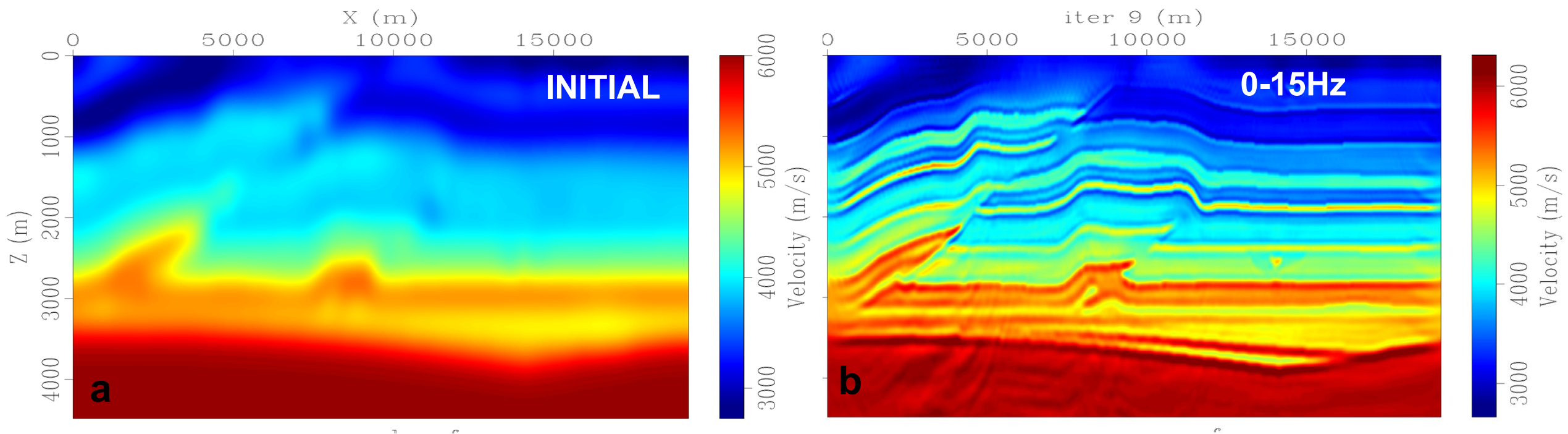




Foothills model (from topography)

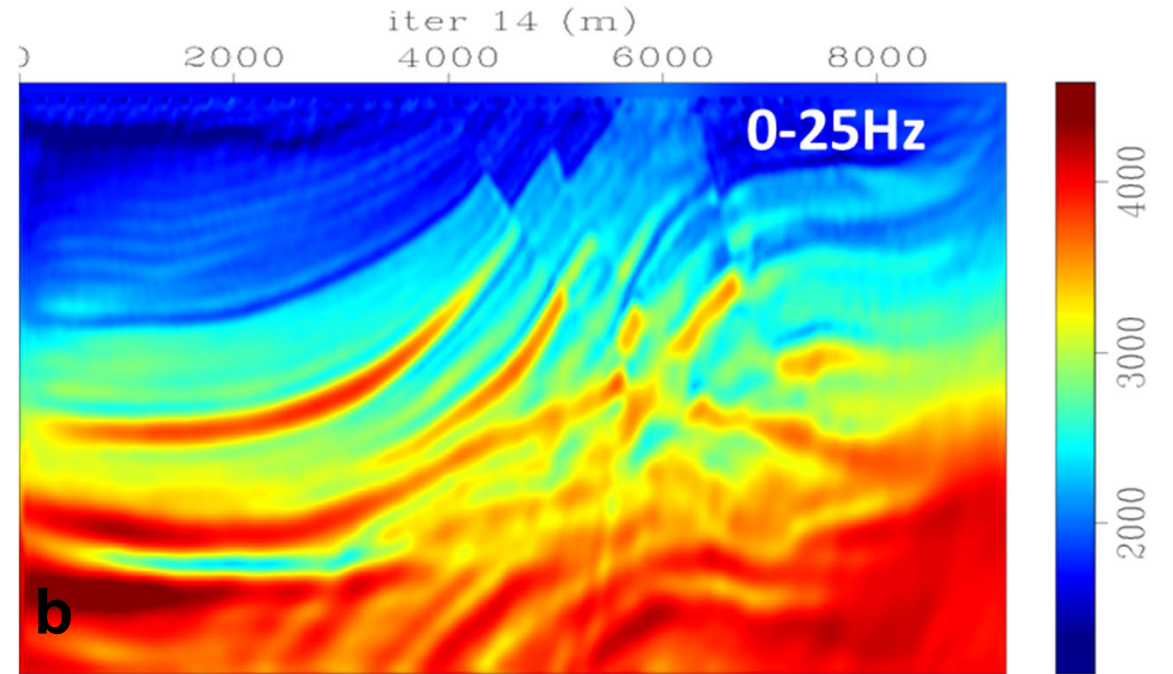
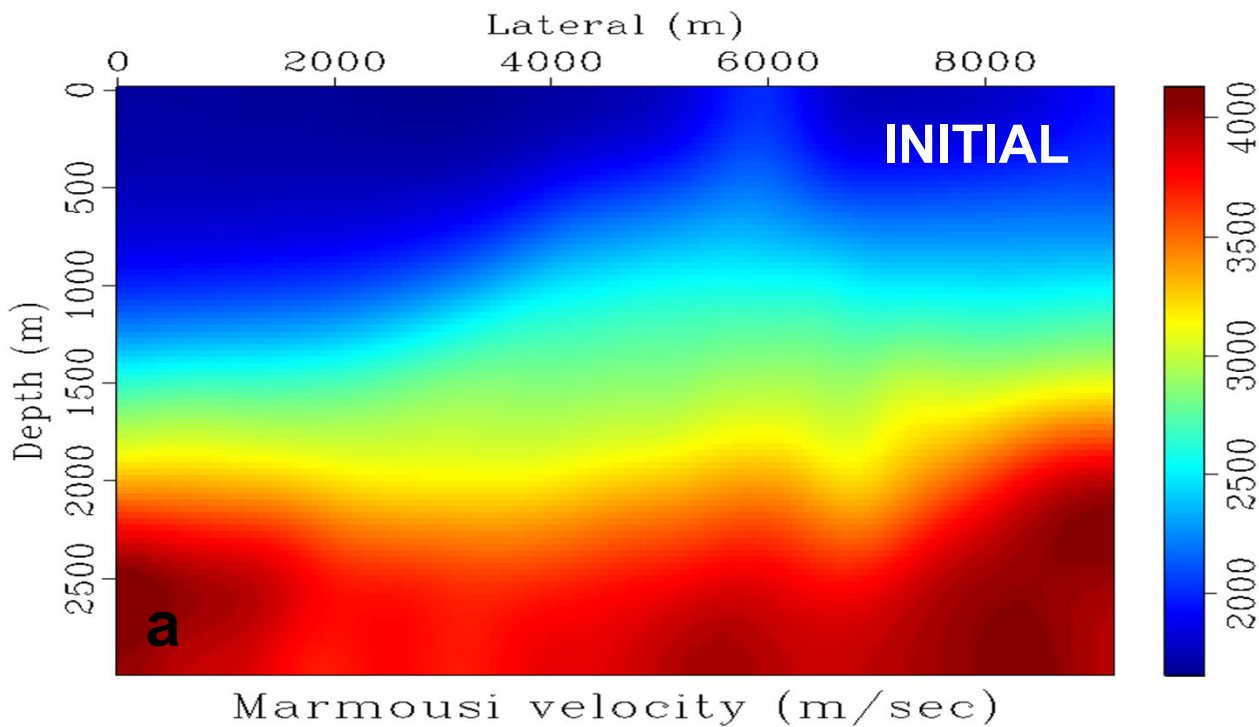
script: **emodel94segyc**







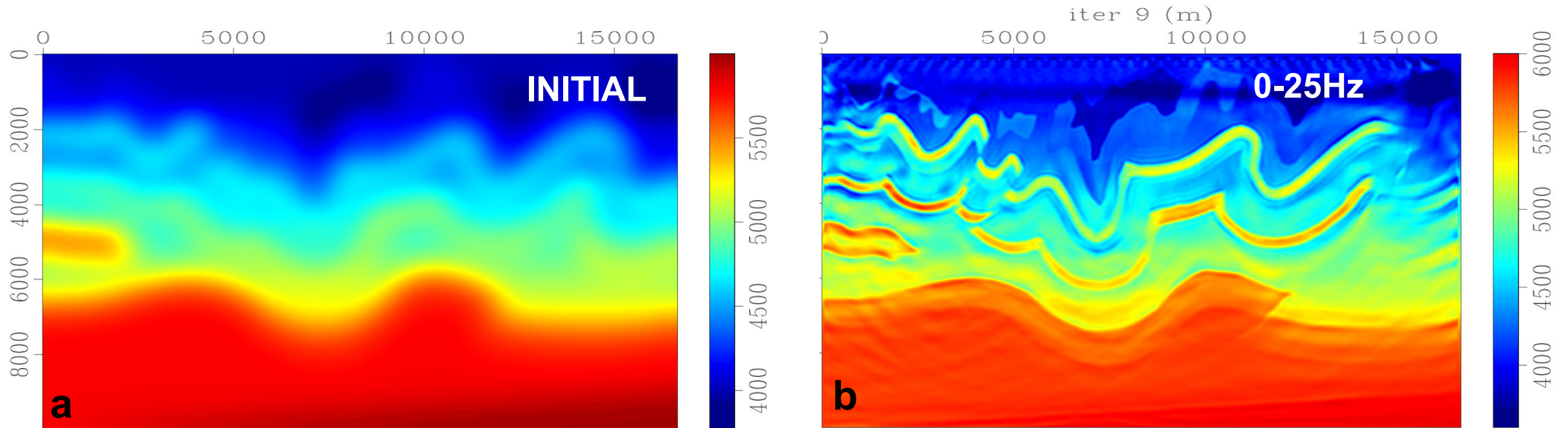
Data generated in a fine grid (8x8) inversion done in coarser grids.





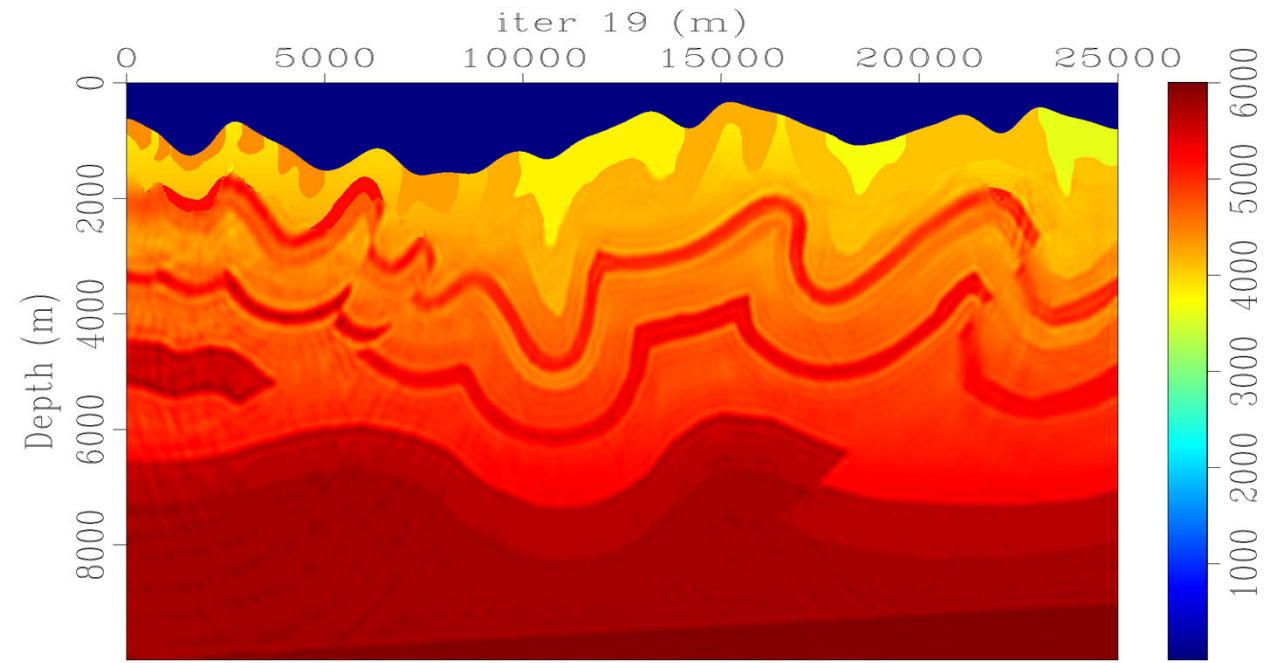
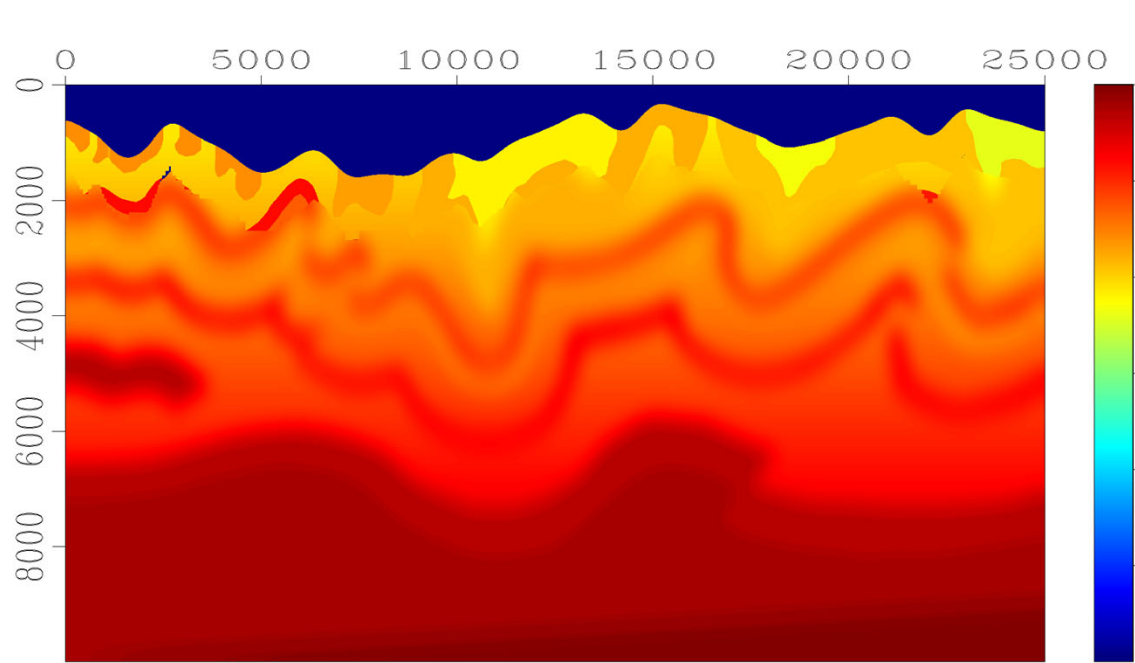
Foothills from datum (multigrid -> no inverse crime)

Data generated in a fine grid (8x8) inversion done in coarser grids.



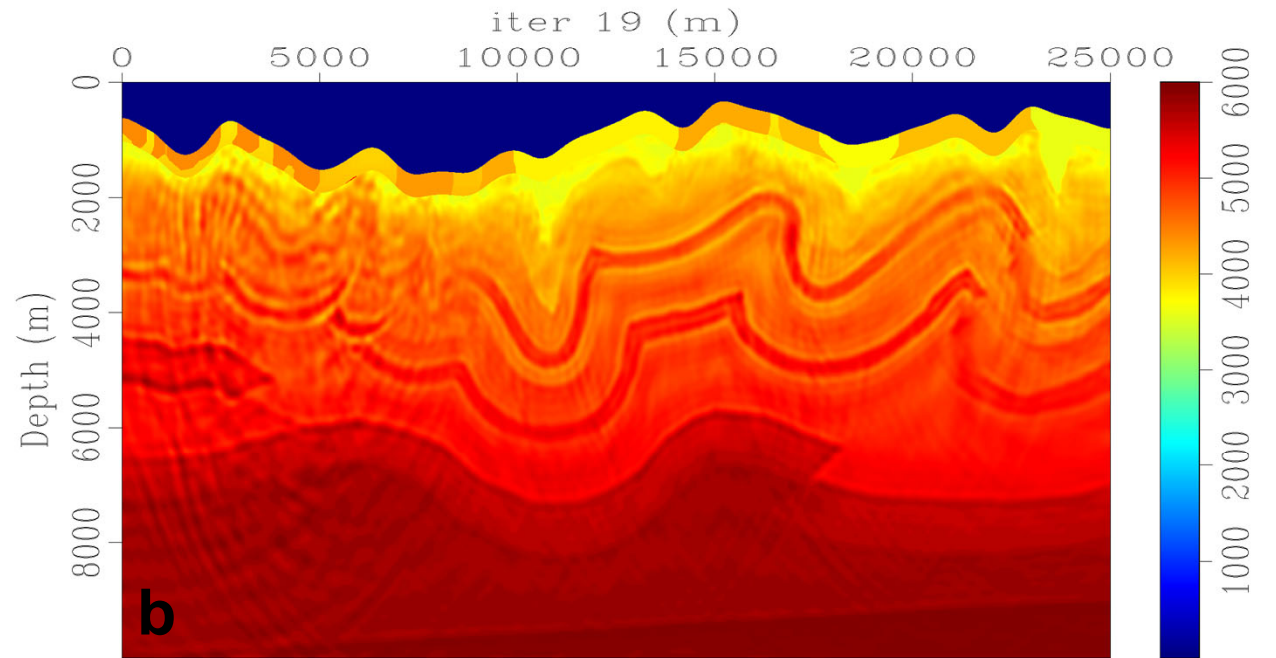
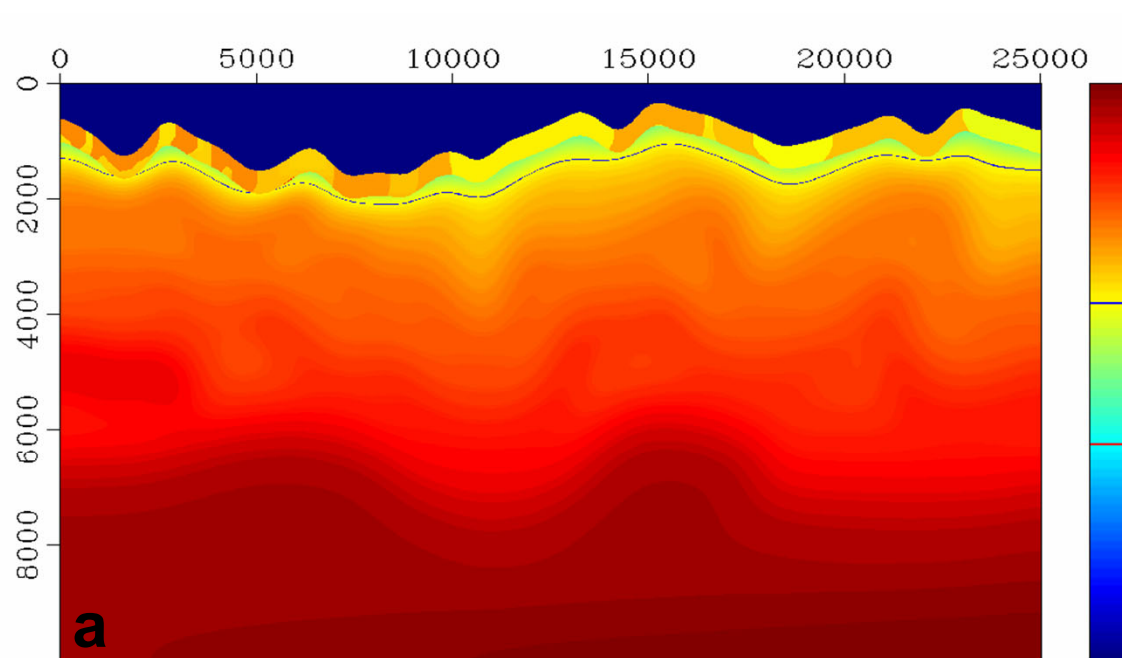


Foothills from topography (harder but inverse crime)





Foothills from topography (harder but inverse crime)





rtm vs fwi

