Forward modeling in elastic media using SINTEF Tiger and AMM method

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Motivation

i. We seek a robust anisotropy forward modeling tool
ii. AVAZ modeling and interpretation of anisotropic models
iii. For future fracture parameter estimations

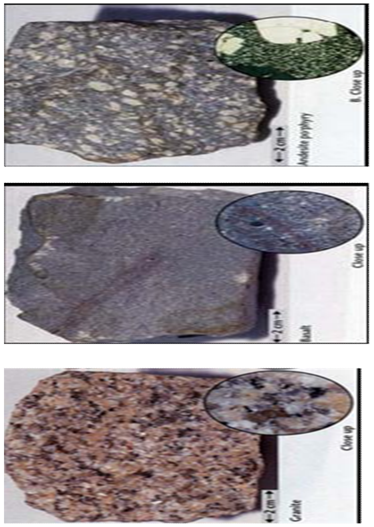
Objective

i. SINTEF Tiger finite difference modeling toolbox
ii. P.F. Daley's Reflectivity finite-difference code
iii. AVO analysis of results
iv. AVAZ analysis @ 3 different azimuths

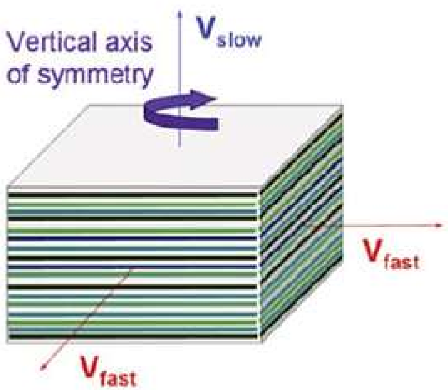
Outline

- Anisotropy in Rocks
- Parameterization
- Forward Modeling tools
- Model Parameter Estimation
- Amplitude Analysis
- Conclusion

Anisotropy in Rocks



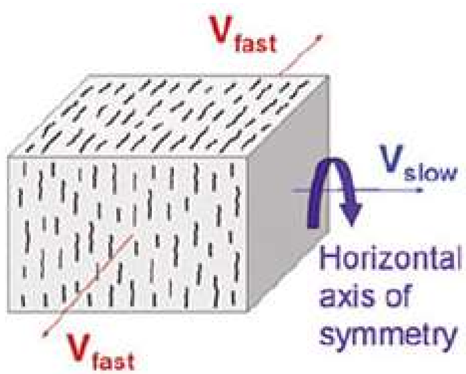
Parameterization



$$\rho v_P^2(\theta) = \frac{1}{2}\left[C_{33} + C_{44} + \left(C_{11} - C_{33}\right)\sin^2\theta + D\right]$$

$$\rho v_{SV}^2(\theta) = \frac{1}{2}\left[C_{33} + C_{44} + \left(C_{11} - C_{33}\right)\sin^2\theta - D\right]$$

$$\rho v_{SH}^2(\theta) = C_{44}\cos^2\theta + C_{66}\sin^2\theta$$



$$D = \Big\{\left(C_{33} - C_{44}\right)^2 + 2\left[2\left(C_{13} + C_{44}\right)^2 - \left(C_{33} - C_{44}\right)\left(C_{11} + C_{33} - 2C_{44}\right)\right]\sin^2\theta + \left[\left(C_{11} + C_{33} - 2C_{44}\right)^2 - 4\left(C_{13} + C_{44}\right)^2\right]\sin^4\theta\Big\}$$

C_{ij} – stiffness coefficients
v_i – phase velocity
θ – phase angle

Parametrization (Thomsen, 1984)

Vertical velocities

$$v_{P0} = \sqrt{\frac{C_{33}}{\rho}} \qquad v_{S0} = \sqrt{\frac{C_{44}}{\rho}}$$

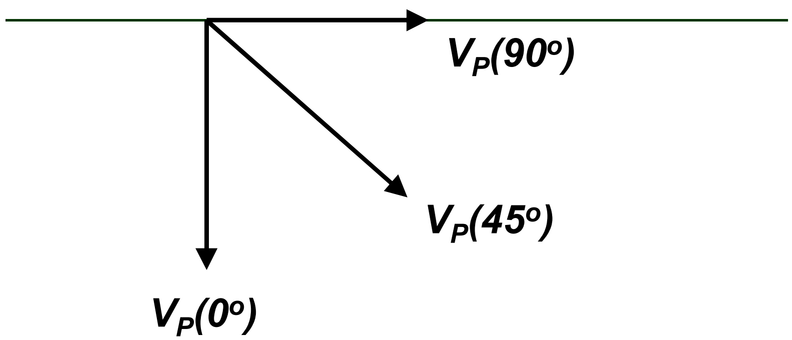
Anisotropy parameters

$$\varepsilon = \frac{C_{11} - C_{33}}{2C_{33}}$$

$$\delta = \frac{(C_{13} + C_{33})^2 - (C_{33} - C_{44})^2}{2C_{33}(C_{33} - C_{44})}$$

$$\gamma = \frac{C_{66} - C_{44}}{2C_{44}}$$

Phase Velocity along symmetry axis and symmetry plane



$$v_{P0} \rightarrow P - \text{wave velocity} \qquad v_{P0} \rightarrow S - \text{wave velocity}$$

$$\varepsilon = \delta = \gamma = 0$$

Isotropy reduction

$$v_P^2\left(\frac{\pi}{2}\right) = v_{P0}^2\left(1+2\varepsilon\right)$$

$$v_{SV}^2\left(\frac{\pi}{2}\right) = v_{S0}^2$$

$$v_{SH}^2\left(\frac{\pi}{2}\right) = v_{S0}^2\left(1+2\gamma\right)$$

Propagation along Isotropy

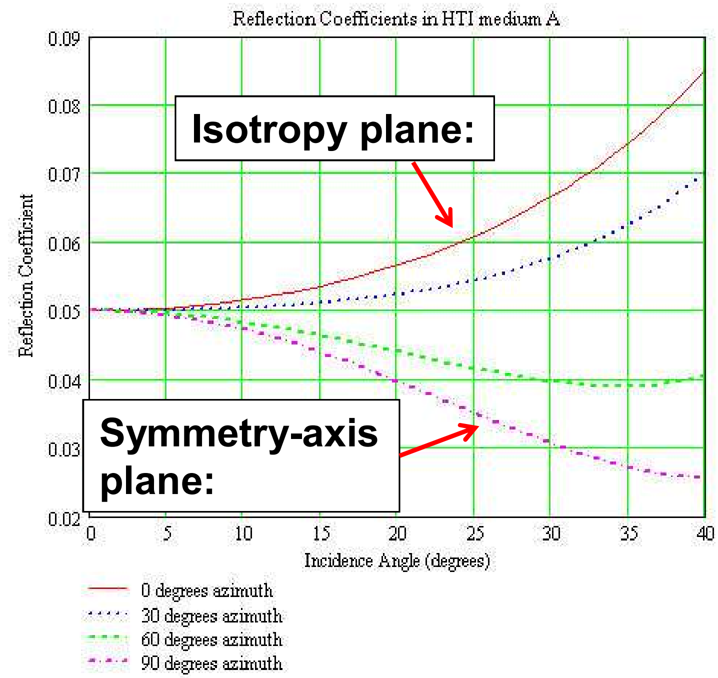
Ruger Approximation

$$R_{HTI} = A + \left(B + B_{HTI}\cos^2\phi\right)\sin^2\theta$$
$$\cdots + \left(C + C_{HTI}\cos^2\phi\right)\sin^2\theta\tan^2\theta$$

where:

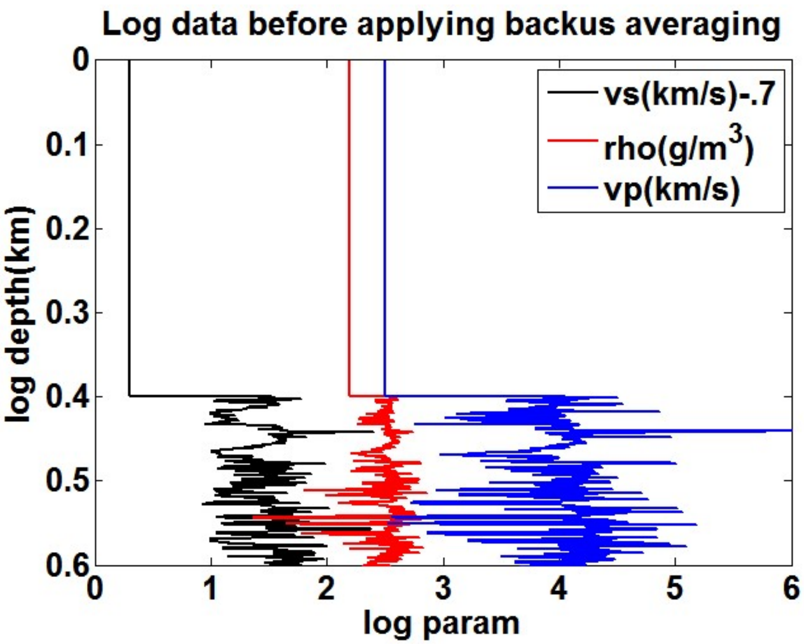
$$B_{HTI} = \frac{1}{2}\left[\Delta\delta^{(V)} + 8\left[\frac{V_S}{V_P}\right]^2\Delta\gamma\right],$$

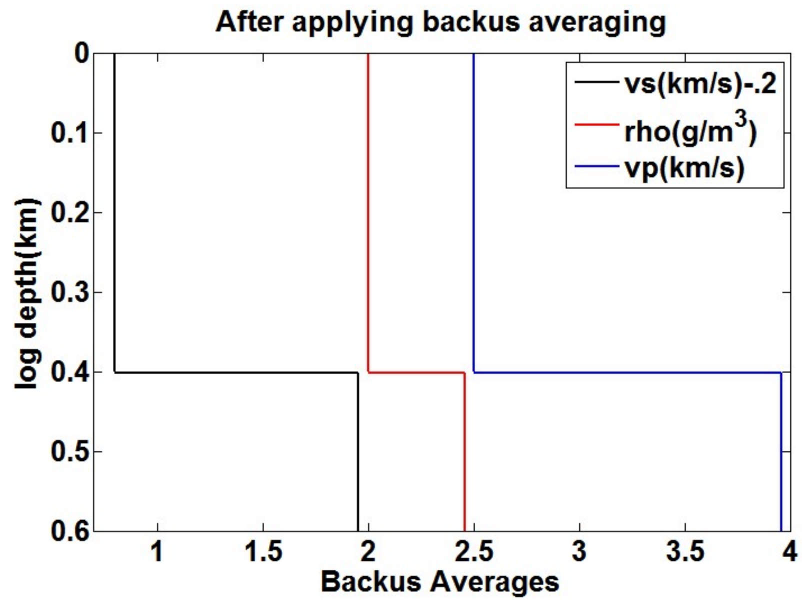
$$C_{HTI} = \frac{1}{2}\left[\Delta\delta^{(V)}\sin^2\phi - \Delta\varepsilon^{(V)}\right]$$



The reflection coefficients for a model where only γ changes, as a function of incidence angle for 0, 30, 60 and 90 degrees azimuth.

Model Parameterization

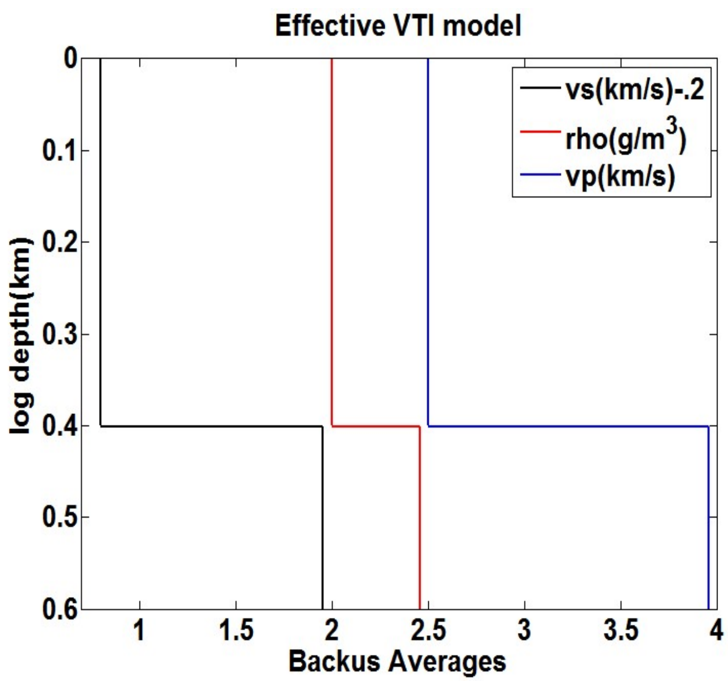


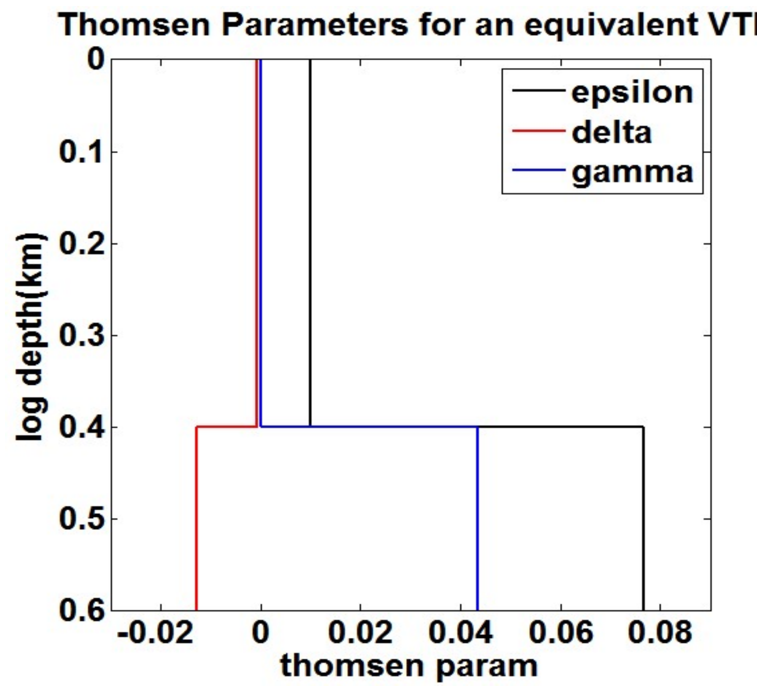


c = 1.0e+10 *

4.2513	1.6329	1.5549	0	0	0
1.6329	4.2513	1.5549	0	0	0
1.5549	1.5549	3.9115	0	0	0
0	0	0	1.1550	0	0
0	0	0	0	1.1550	0
0	0	0	0	0	1.3092

Model Parameterization

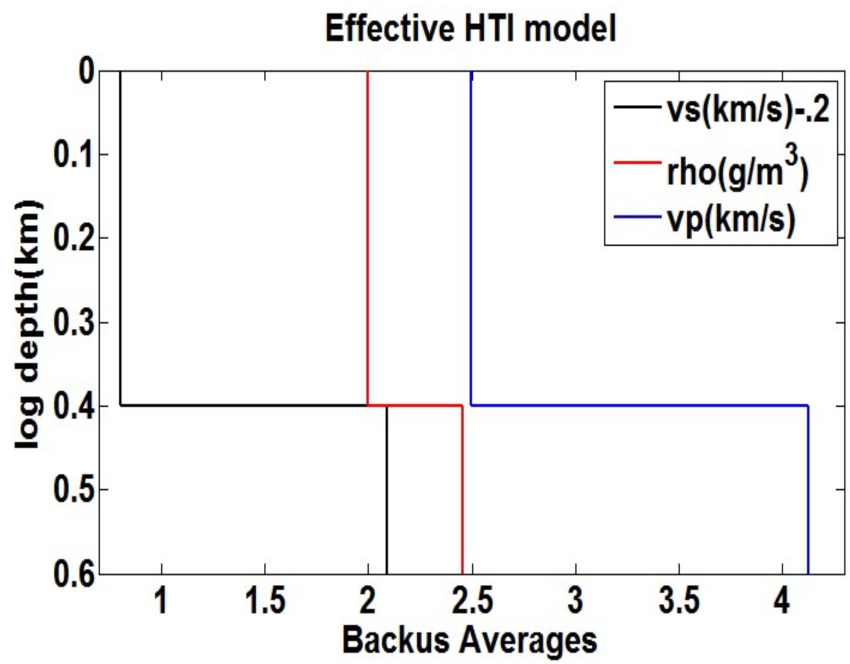


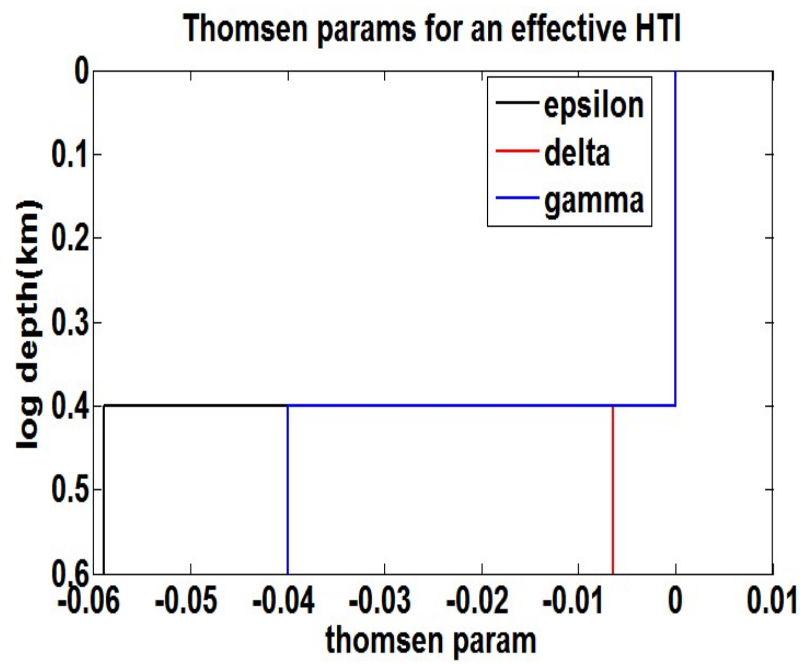


VTI(vp,vsh,vsv])= (3.9591 2.1513 2.1513) * 1.0e+03

Thomsen_VTI = 0.0434 0.0668 -0.0118

Model Parameterization

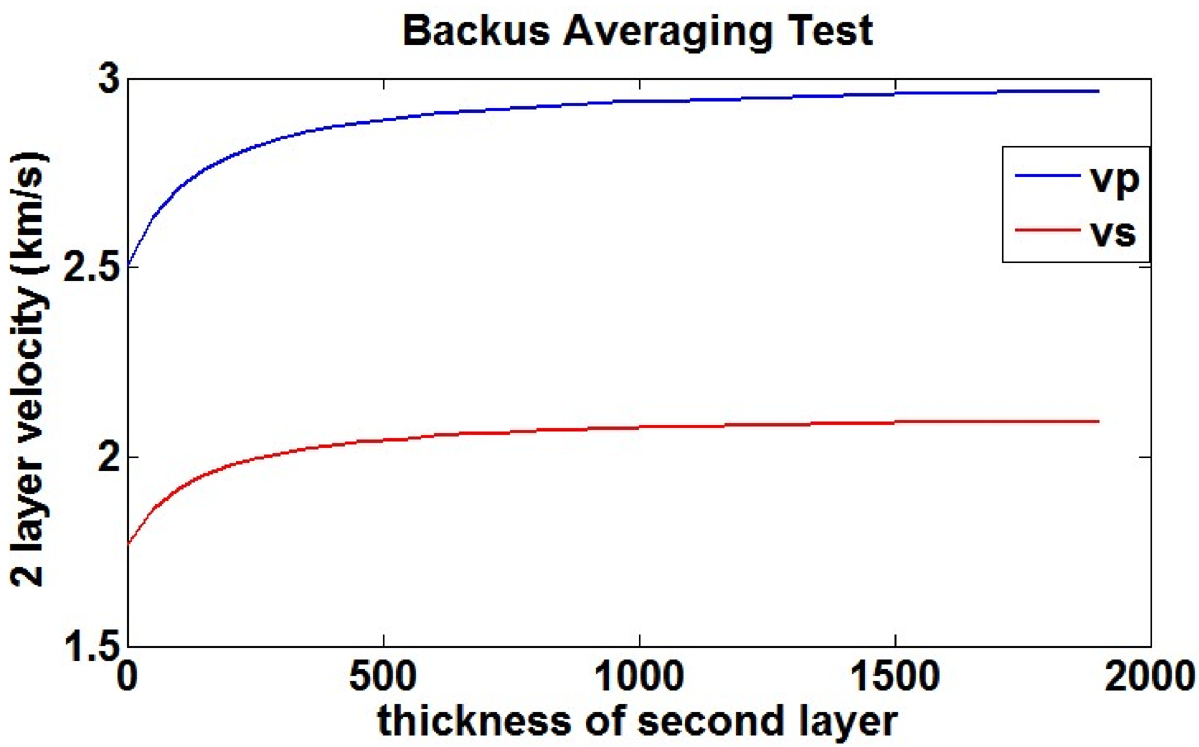




HTI(vp2,vsh2,vsv2) = (4.1275 2.2904 2.1513) * 1.0e+03

Thom_HTI = -0.0400 -0.0589 -0.0064

Averaging Test



Forward Modeling tools

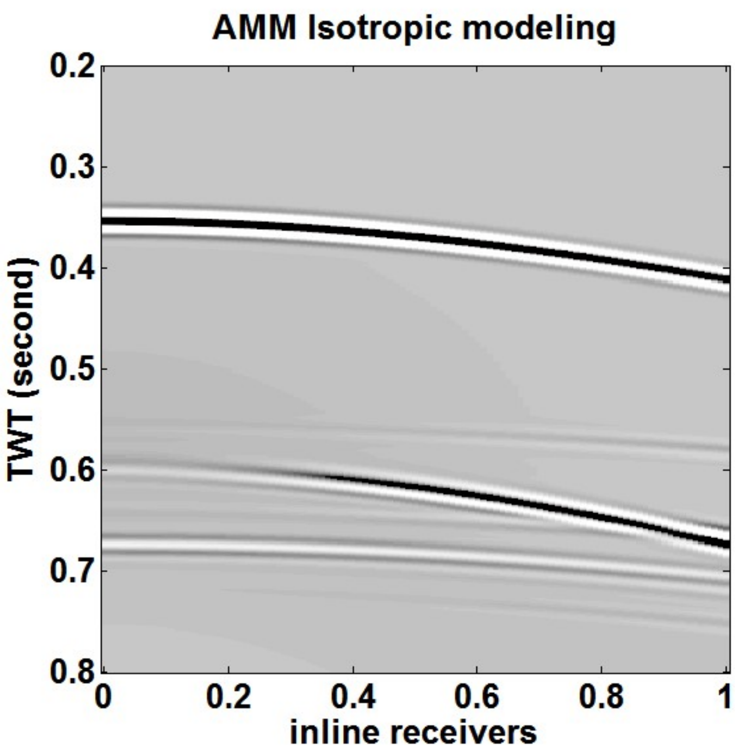
AMM

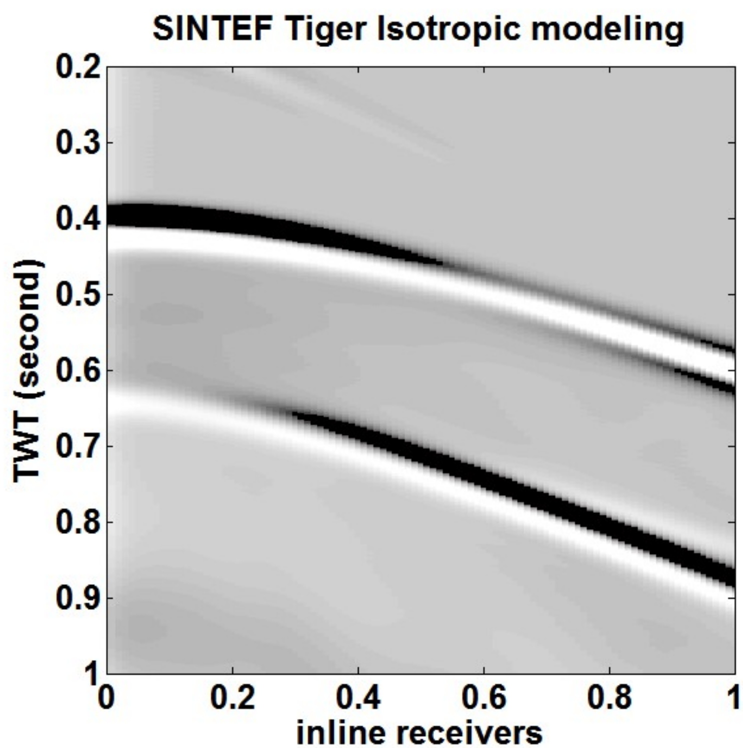
- Reflectivity-Finite Difference Code (by P.F Daley)
- Hybrid method
- Reflectivity method (Fuch and Mueller) with finite difference in depth or time
- Source wavelet is Gabor
- Fast
- Isotropic codes works well but TI code needs some work
- Amplitude computations need to be calibrated

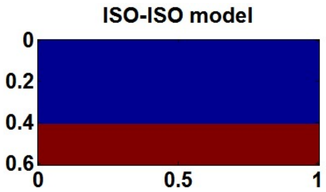
SINTEF TIGER

- Finite difference method
- Fast (depending on grid and/or model size)
- Options for importing anisotropic models
- Has options for anelastic modeling
- Explosive source or dipole source
- Grid dispersion well taken care of
- Robust

Isotropic modeling

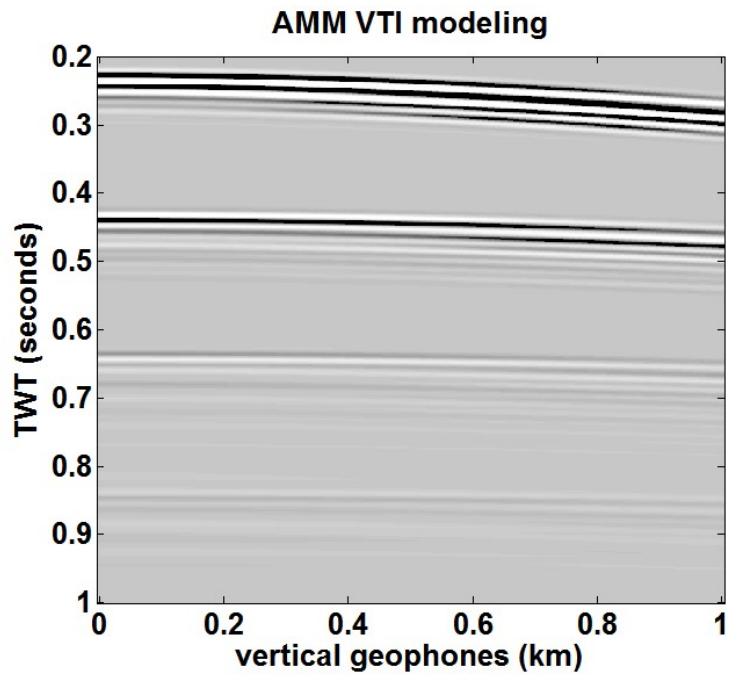


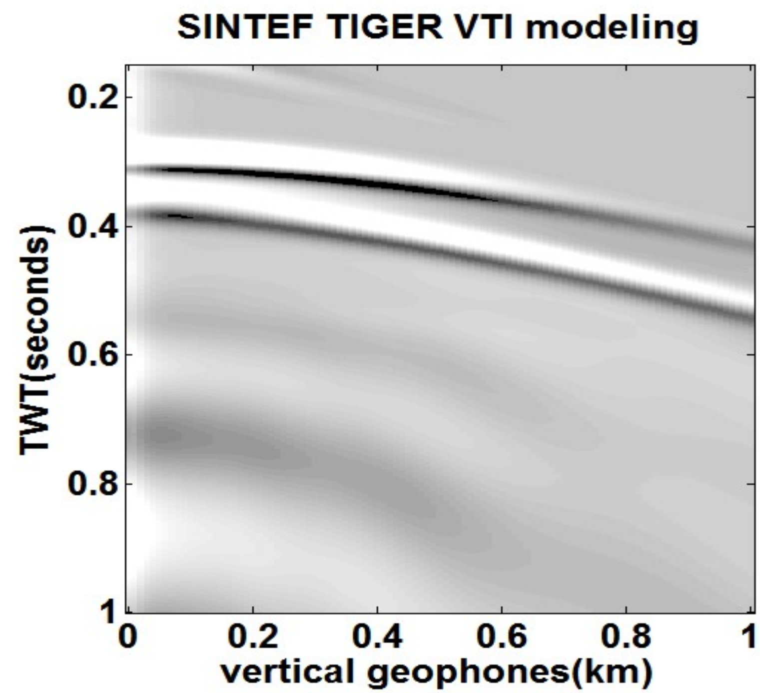


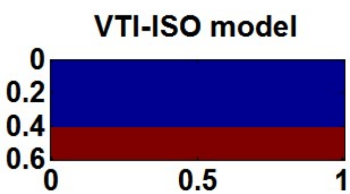



```
rho=[2200 2495]; vp=[2500 4128]; vs=[1000 2290];
delta=[0 0]';      epsilon=[0 0]';   gamma=[0 0]';
```

Effective VTI modeling

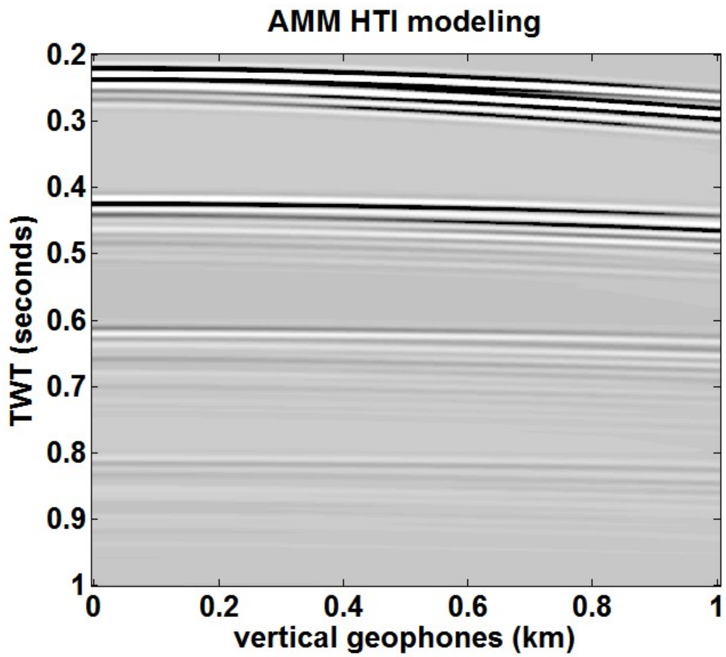


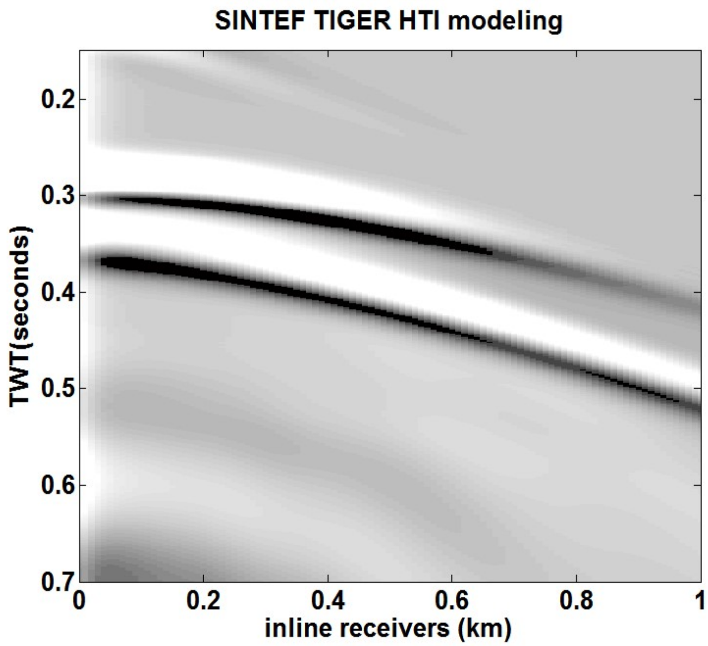


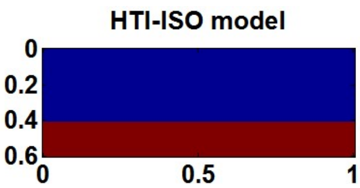



```
den=[2.495 2.200]';  alpha=[3.959 2.500]'; beta=[2.151 1.000]';
delta=[-0.00118 0]'; epsilon=[0.0668 0]';  gamma=[0.0434 0]';
```

Effective HTI modeling

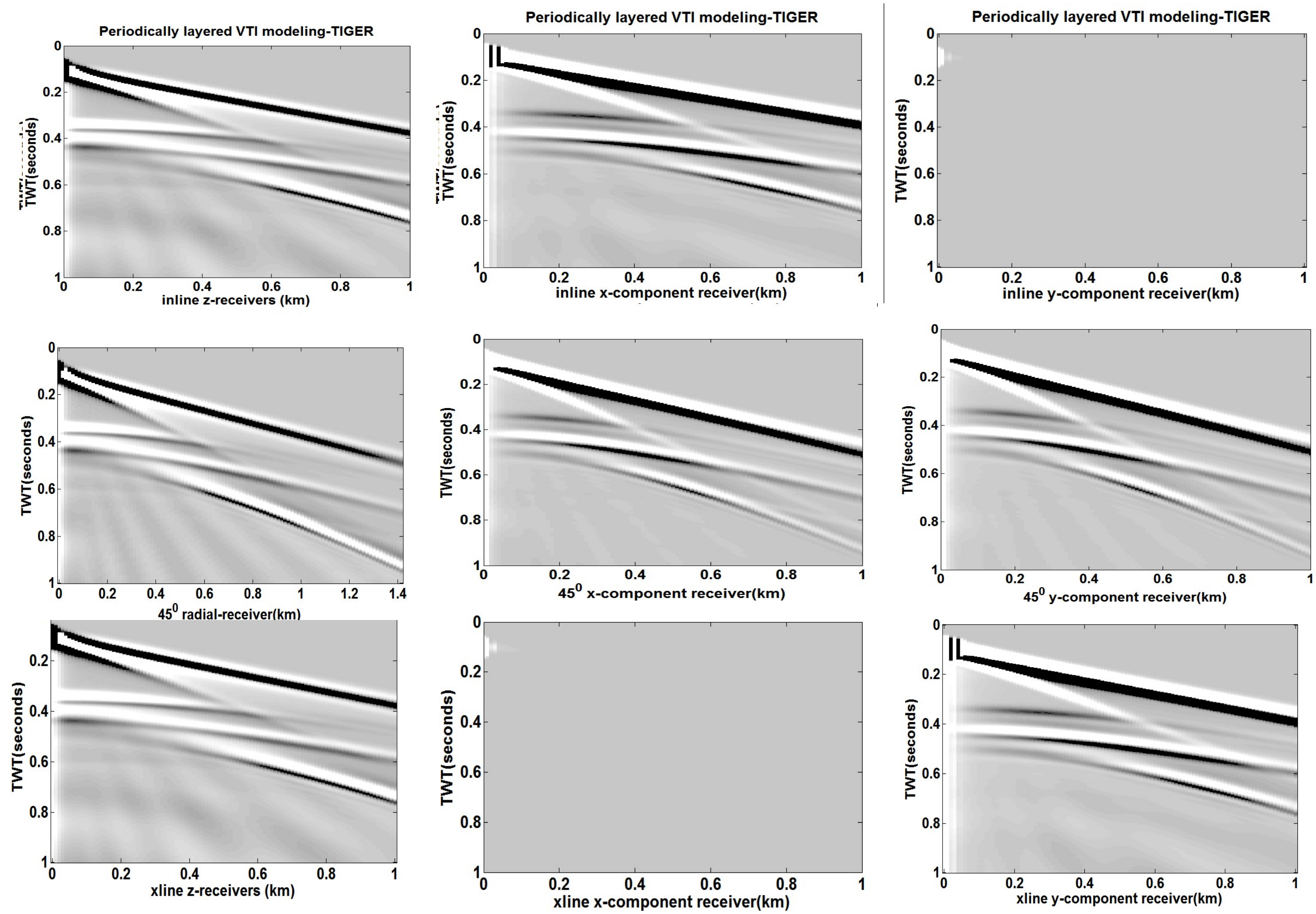


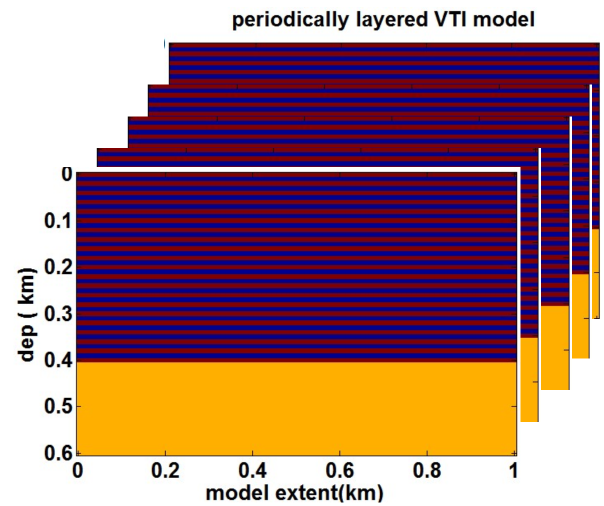




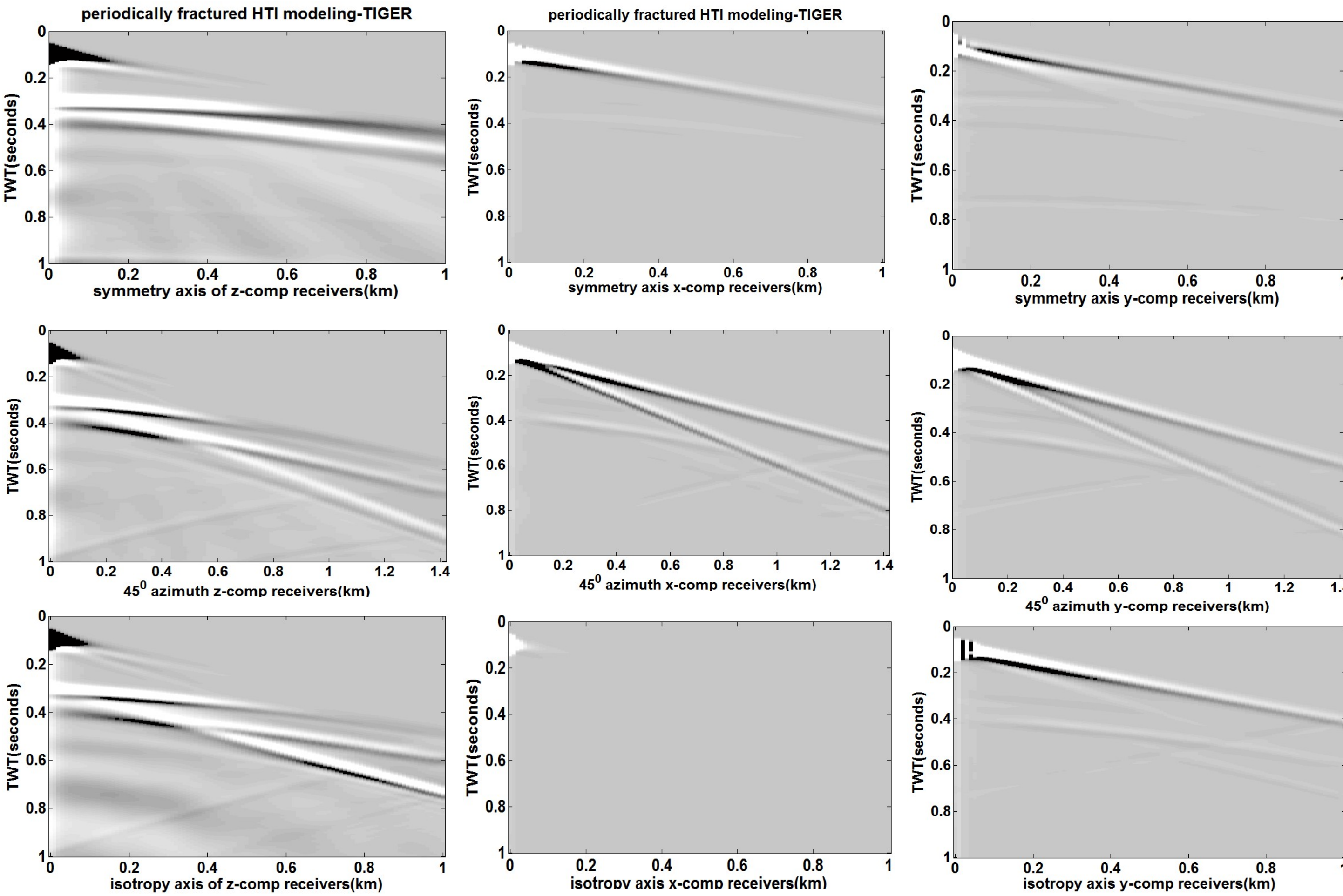

```
den=[2.495 2.200]'; alpha=[4.128 2.500]'; beta=[2.290 1.000]';
delta=[-0.0064 0]'; epsilon=[-0.0589 0]'; gamma=[-0.04 0]';
```

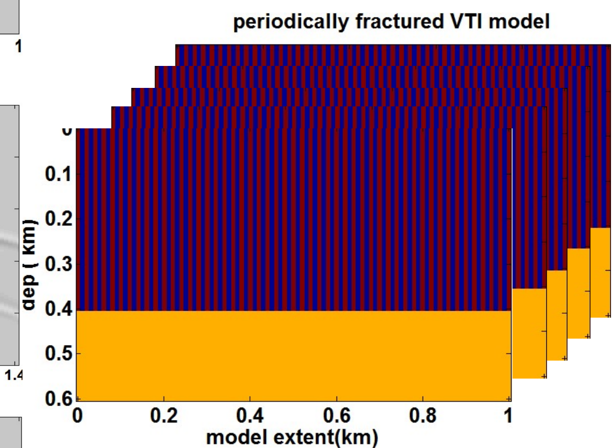
Overburden layered VTI modeling - TIGER



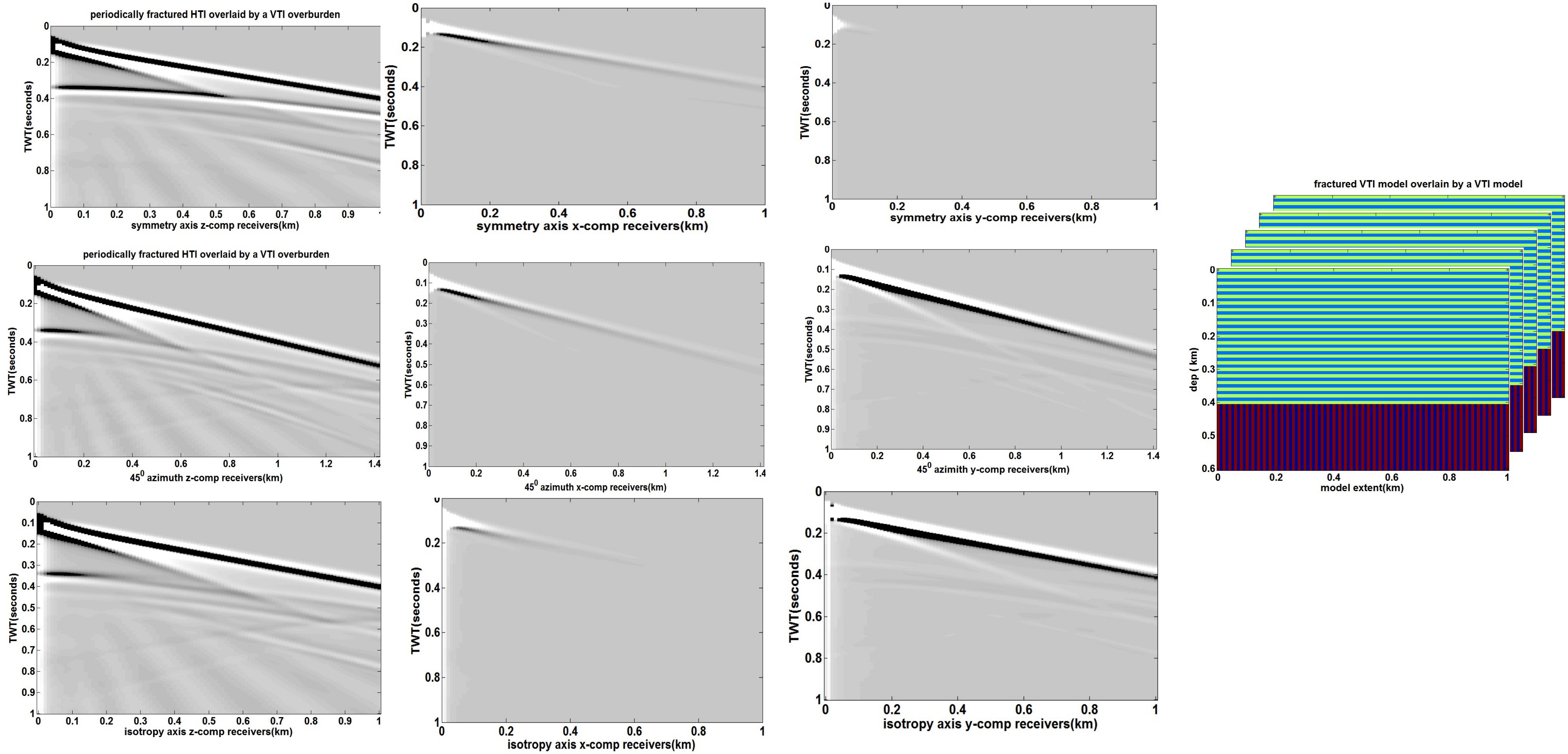


Fractured HTI modeling - TIGER

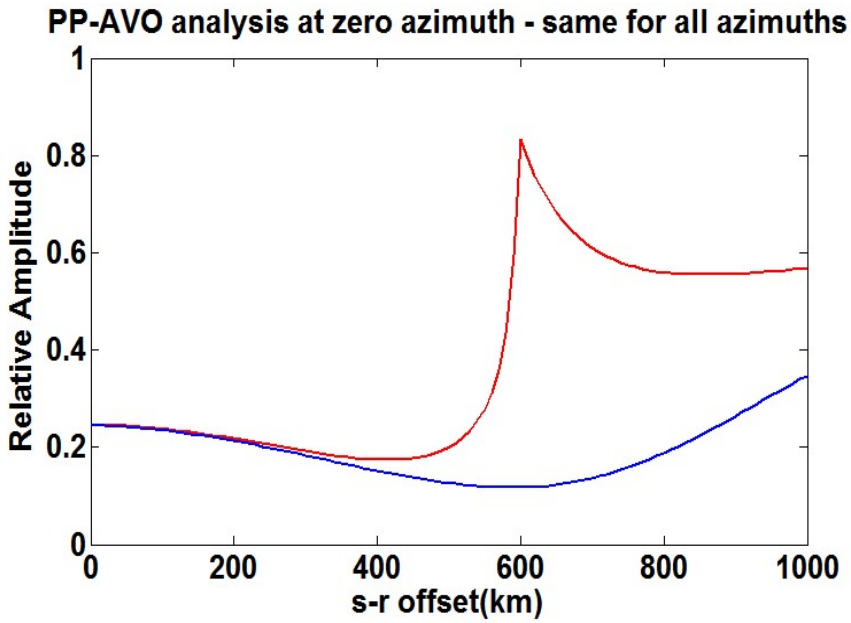


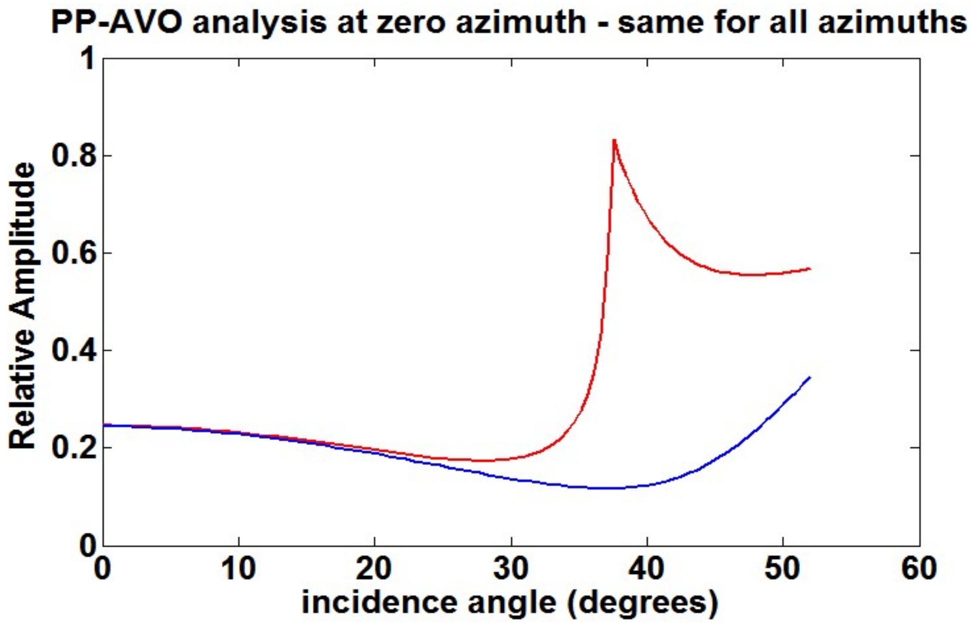


Fractured HTI medium overlain with layered VTI modeling - TIGER

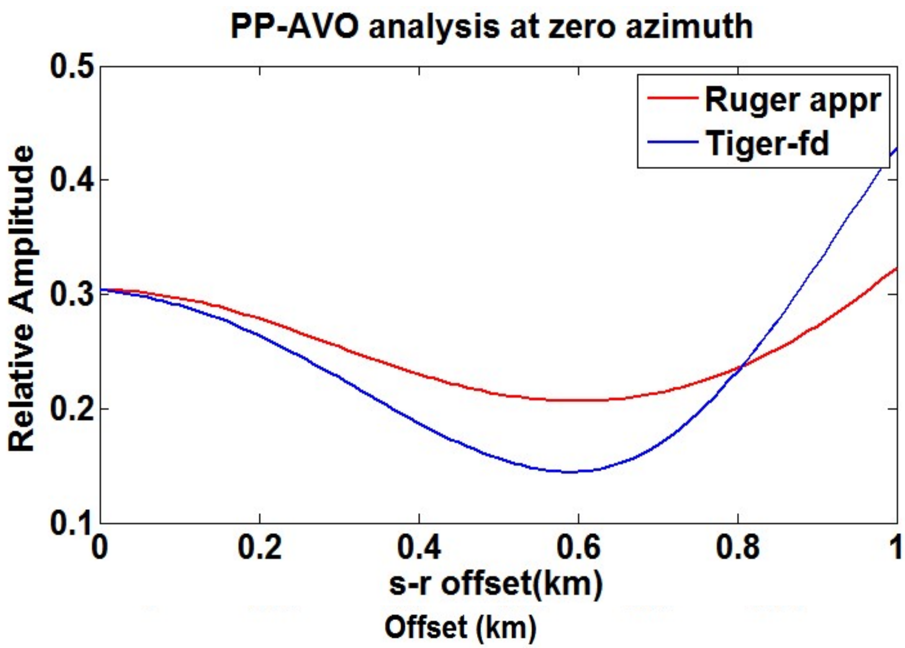


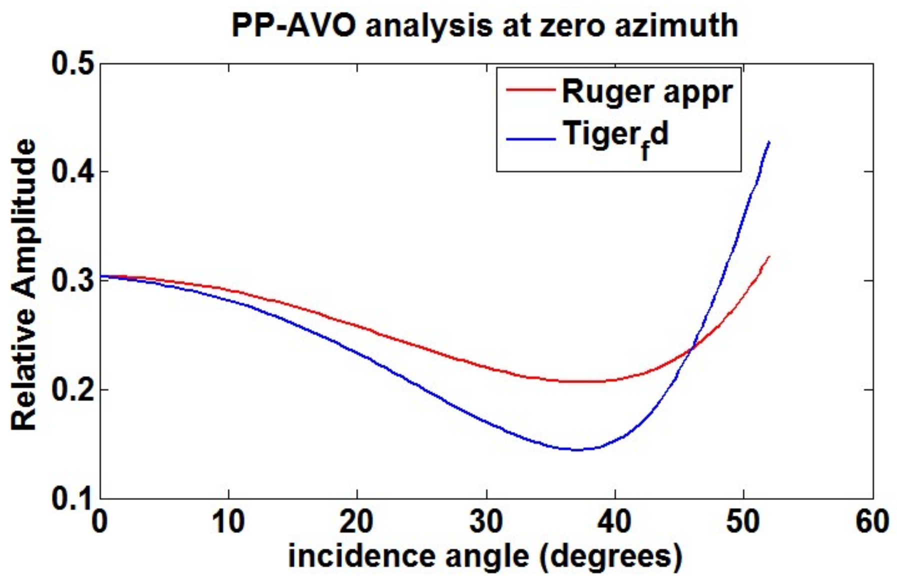
Amplitude Analysis



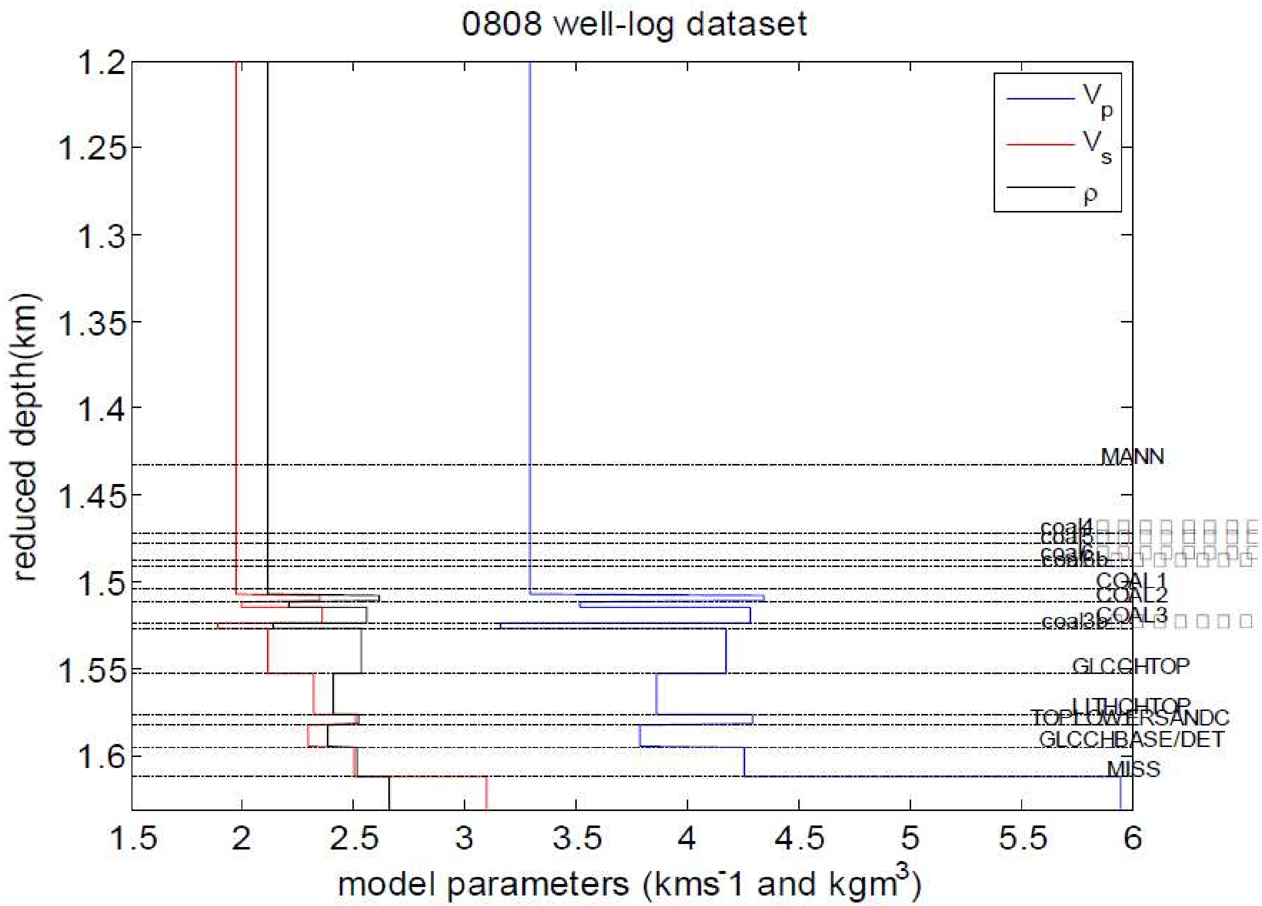


Amplitude Analysis

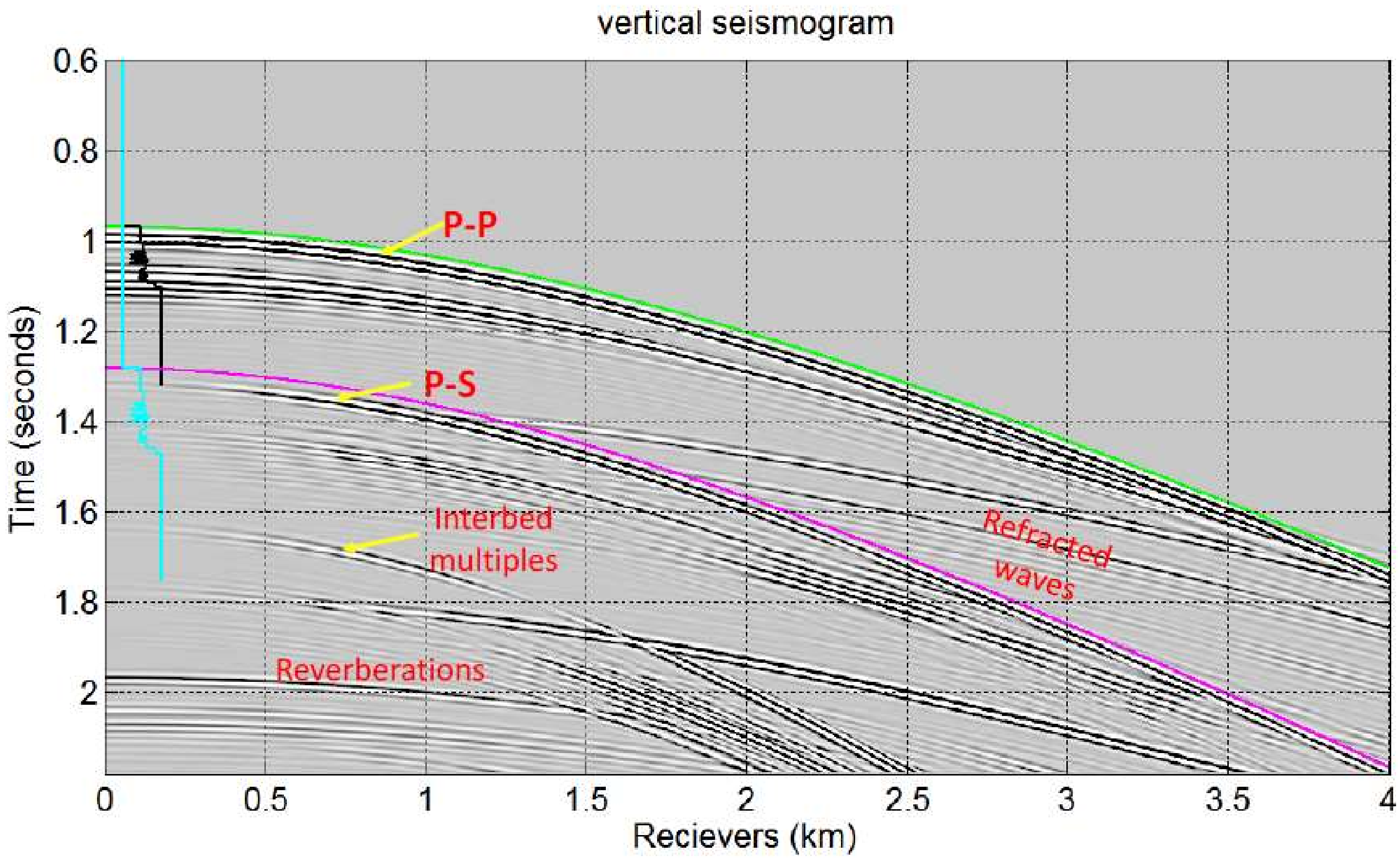




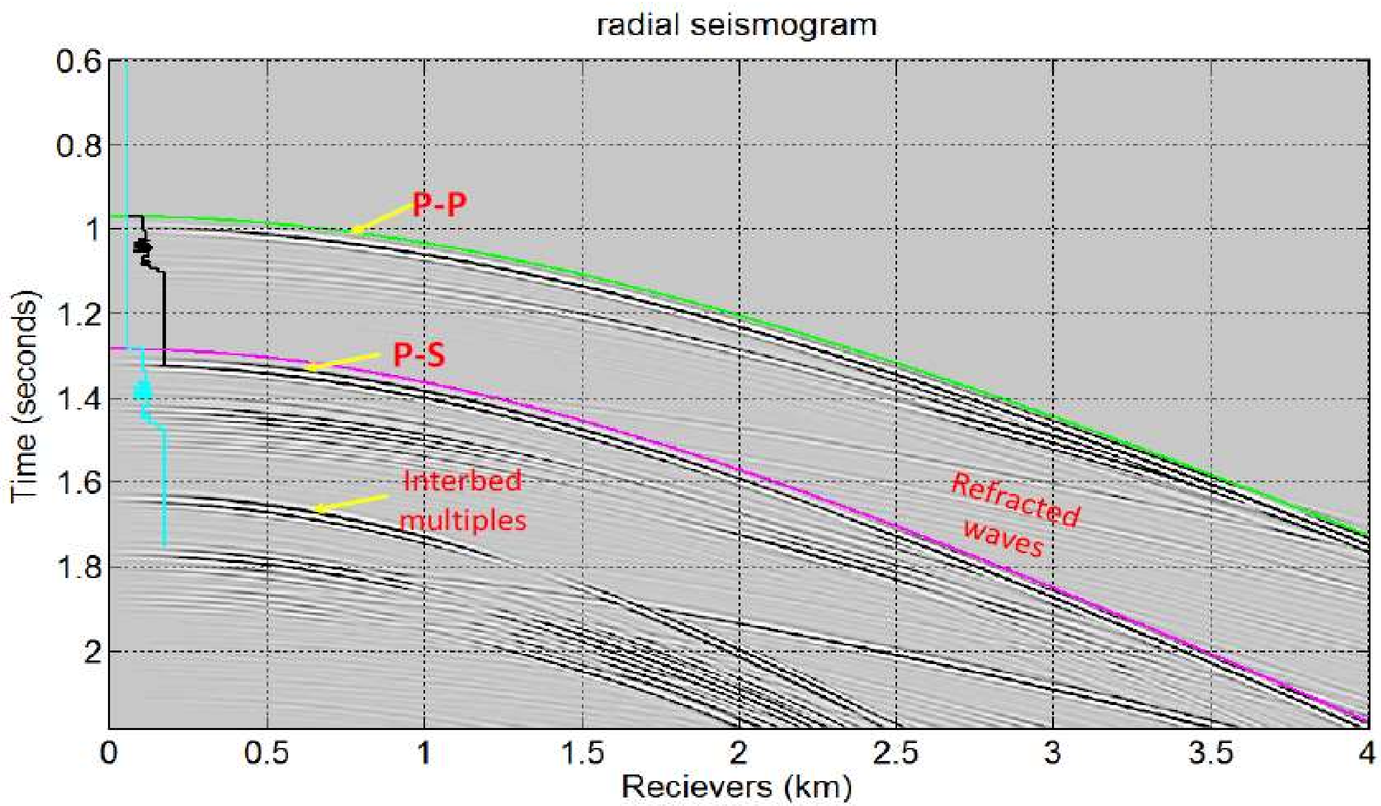
Previous Amplitude Analysis using AMM



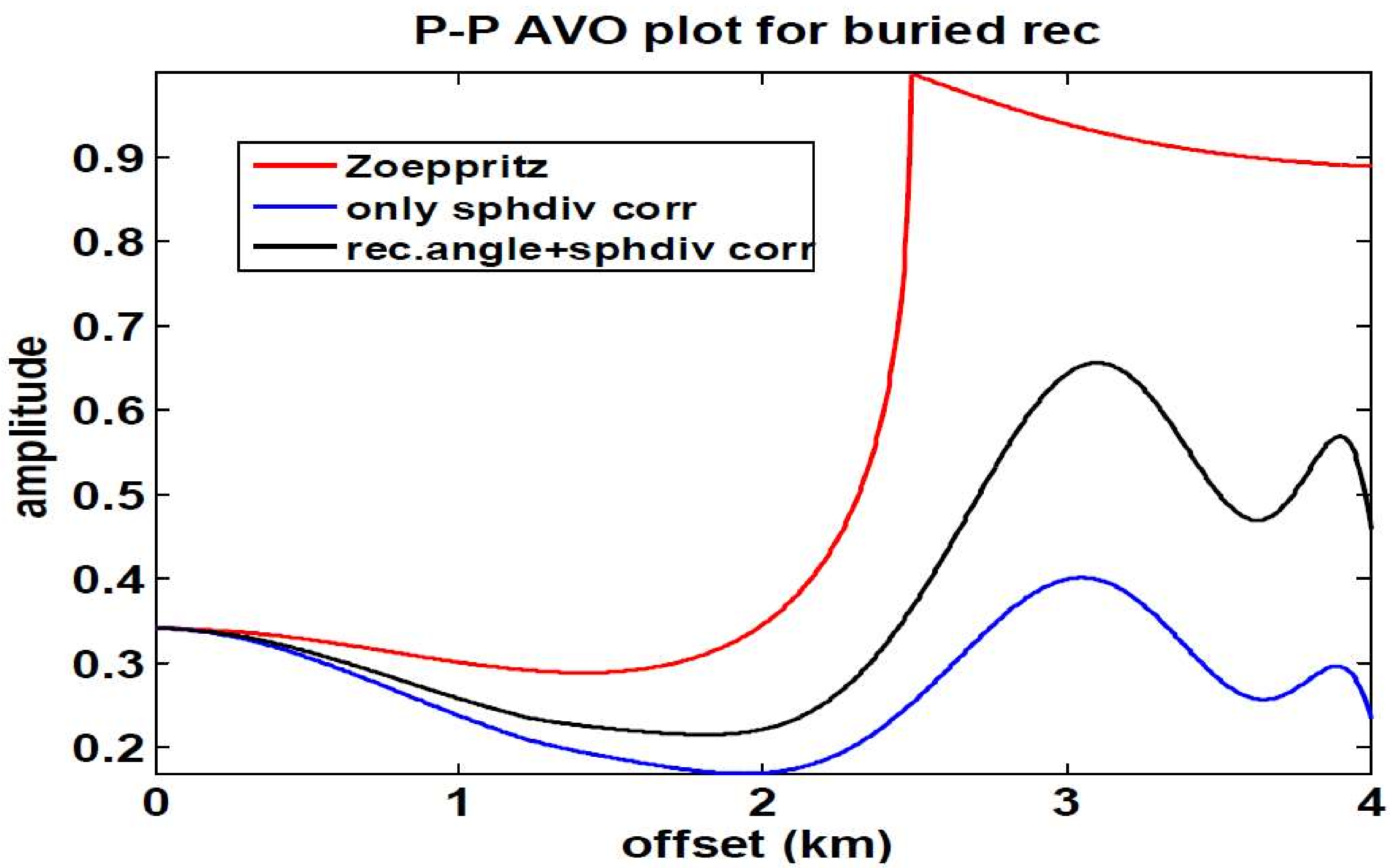
Previous Amplitude Analysis using AMM



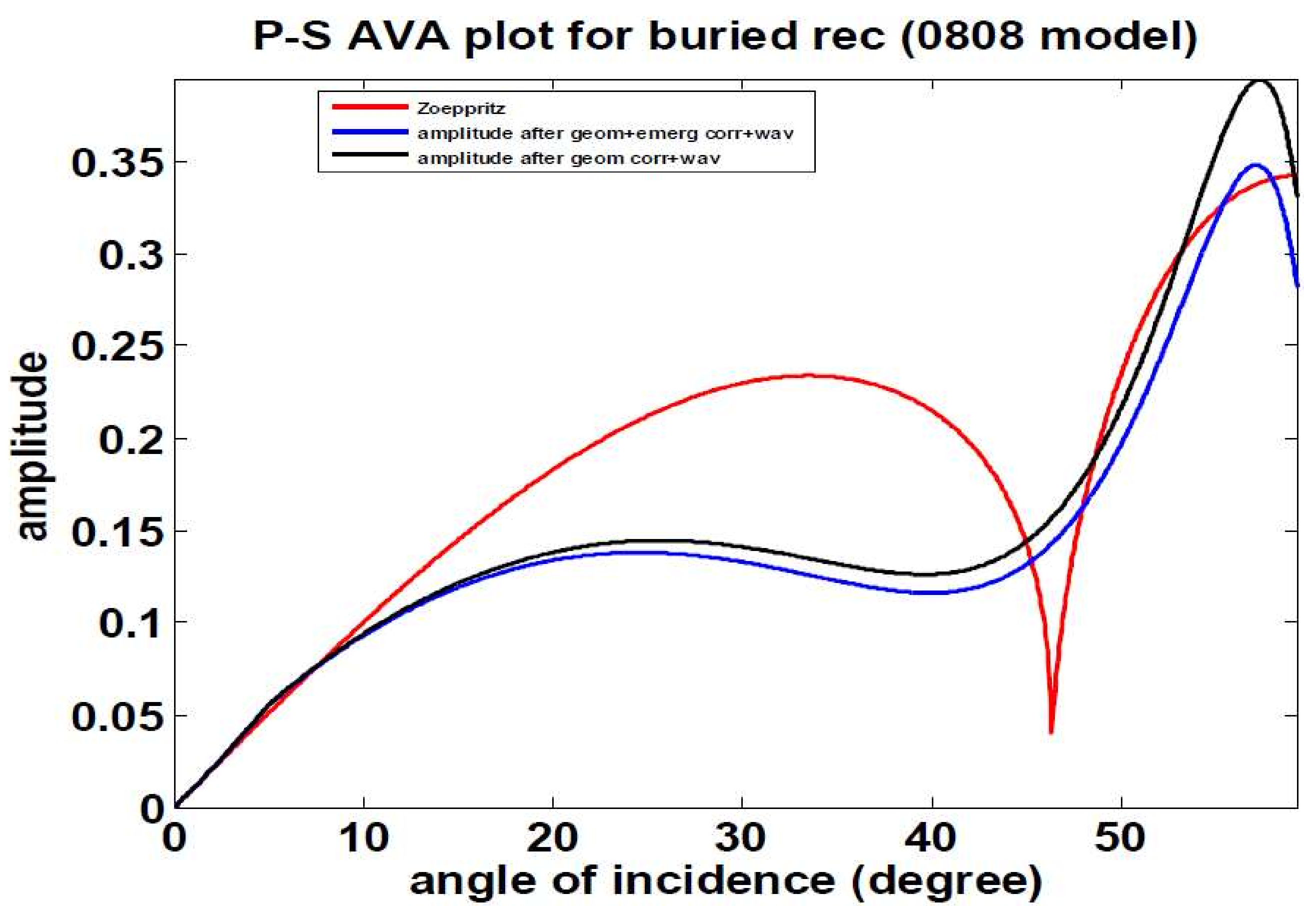
Previous Amplitude Analysis using AMM



Previous Amplitude Analysis using AMM



Previous Amplitude Analysis using AMM



Work in Progress

1. Further AVAZ analysis and comparison
   I. Tiger FD
   II. AMM (new modeling)
   III. Ruger
2. Focus on processing Tiger FD result for fractured HTI media

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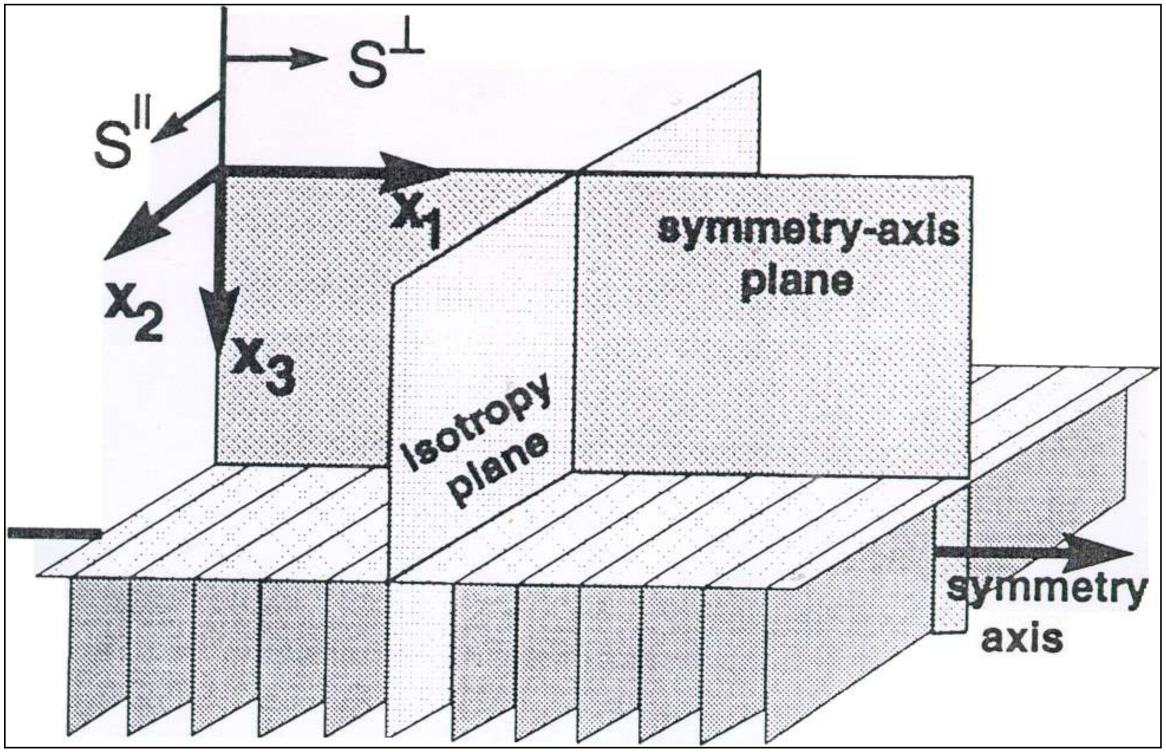
Conclusion

- Backus averaging was used to estimate averages of elastic parameters and Thomsen's parameter
- The SINTEF TIGER Finite Difference tool is promising for all range of multicomponent seismic acquisition, processing and interpretation.
- The AMM code works well for isotropic and transversely Isotropy models with vertical symmetry,
- Work is still ongoing to improve its efficiency for anisotropic models.
- Work continues of further AVAZ analysis
- Good News!!! We can now import model into TIGER.

Acknowledgement

- CREWES Sponsors and Director
- Gary Margrave and Pat Daley
- Kevin and Faranak
- Saul
- CREWES Staff
- Students

Questions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S||
x1
x2
x3
symmetry-axis
plane
isotropy
plane
symmetry
axis