Radiation patterns in anisotropic models by Kirchhoff modelling/migration and AVO/AZ inversion

Hassan Khaniani* and Daniel Trad
khaniani@ucalgary.ca

Introduction

- We developed a framework of a 3D model waveform inversion using Kirchhoff approximation
- The method is applicable to precritical reflection data acquired from 3D anisotropic media.
- We coupled Kirchhoff based forward modeling, migration for inversion

Approximations

❑ **Traveltime:**
Double Square Root (DSR) of PSTM.

❑ **Amplitude:**
The AVO/AZ of weak contrast anisotropic models.

Objective of this study:

- To reduce the computation time of modeling, migration and inversion in Full Waveform Inversion (FWI).
- To study the uncertainty of the AVO/AZ.
- To provide a tool that other scientists can use to visualize the radiation patterns of an isotropic and anisotropic media.
- To predict and minimize the acquisition artefacts.

Why Kirchhoff approximation?

- PSTM is a practical approach in seismic imaging.
- PSTM provides similar outcome of Reverse Time Migration (RTM) if the model does not have complex structures (e.g., Figure 1).

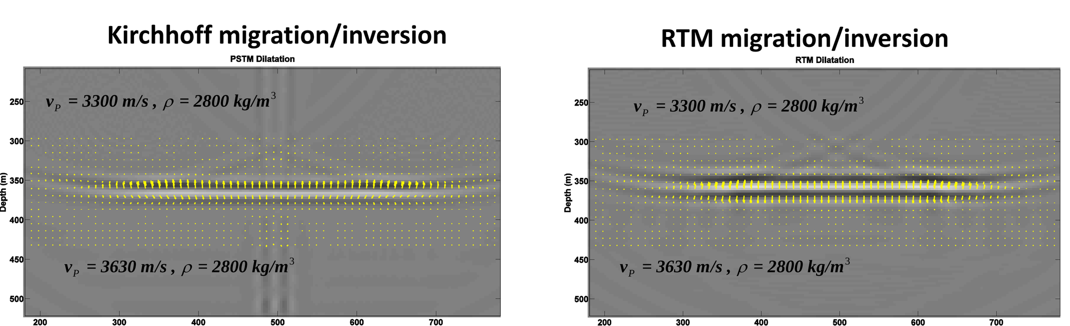

Fig.1. Example of migration and inversion by Kirchhoff and RTM

- The Kirchhoff approximation algorithm is an efficient tool for field data prediction (e.g., Figure 2).

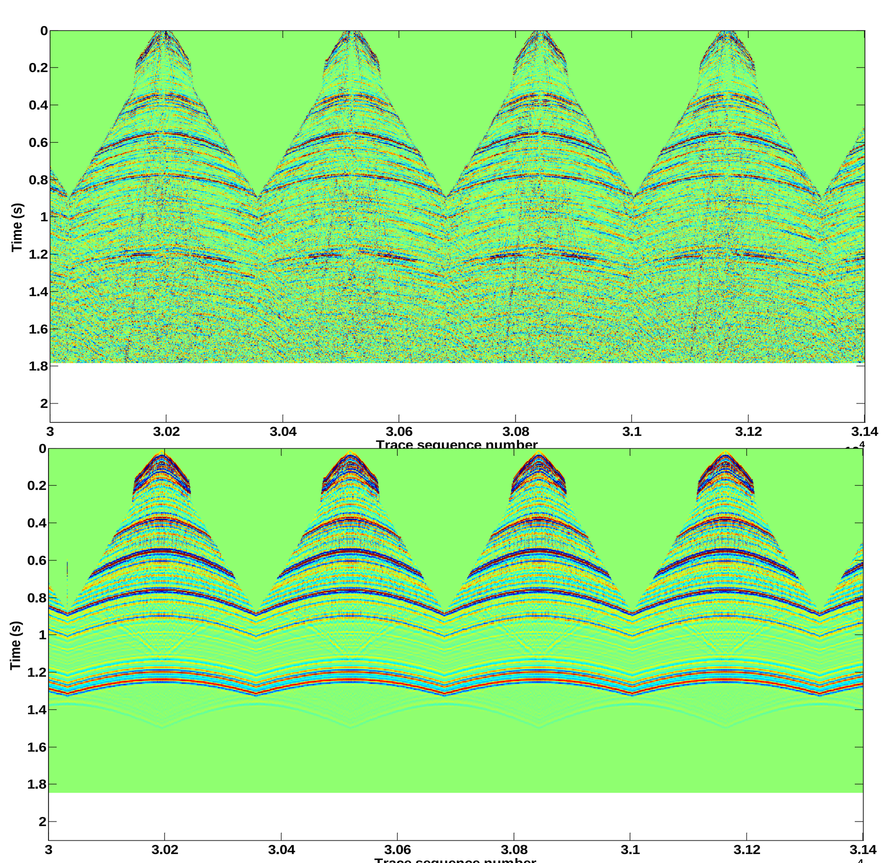

Fig.2. Kirchhoff modeling used for prediction of field data

Why we use AVO/AZ analysis for inversion?

- AVO/AZ is a standard workflow in seismic attribute analysis and hydrocarbon detection.
- The radiation pattern in seismic data is sensitive to subsurface multi-parameters.
- In the framework of FWI, we use the AVO/AZ curve fitting for estimation of the gradient function (Khaniani et. Al., 2015).

How the method is compared to finite difference based FWI?

❑ **Similarity**

Both have iterative framework that include forward modeling and migration
In both approach, the parameters of operators are updated.

❑ **Difference**

- The modeling in FWI is two-way wave equation
- The migration in FWI handles complex structures
- The gradient function in FWI is based on imaging conditions of extrapolated stress but in the Kirchhoff approach the gradient is obtained by least square fitting of radiation patterns of scatterpoints.

Radiation patterns in HTI anisotropic models

- The analysis are based on AVO/AZ approximations of Rüger (1997)
- As shown in Figure 3, the HTI model is characterized by angle of incident and azimuth of axis of symmetry.
- Theoretical formulation of AVO/AZ are evaluated for a target layer at depth of 500 m. Azimuthal variation of HTI parameters are shown in Figure 4 and 5)

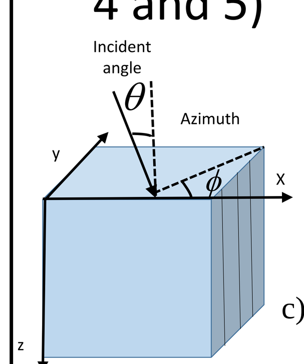

Fig.3. HTI model

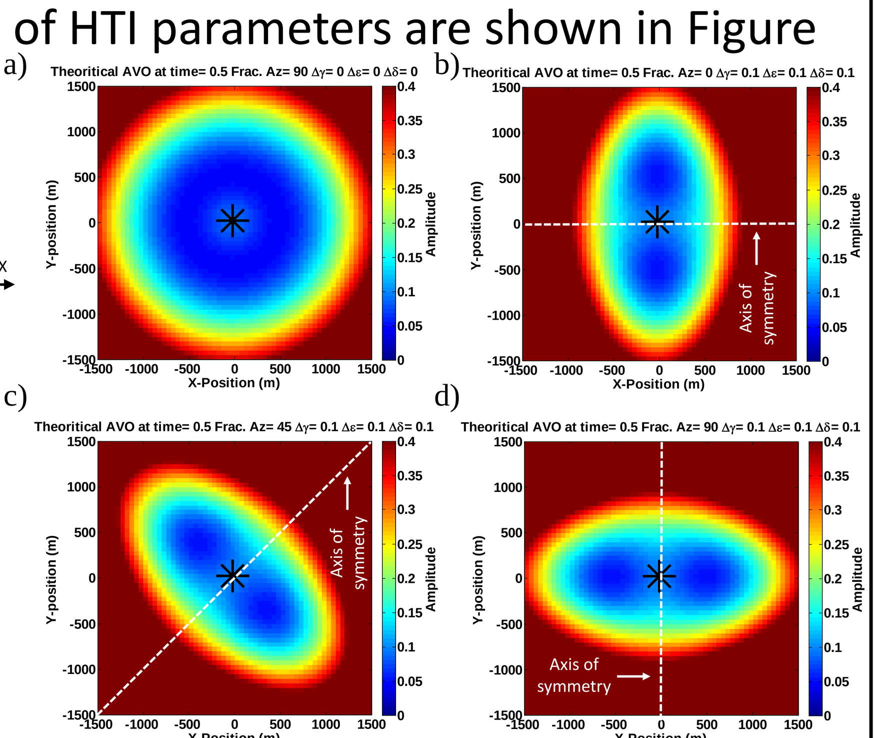

Fig.4. Theoretical evaluation of axis of symmetry on HTI radiation pattern

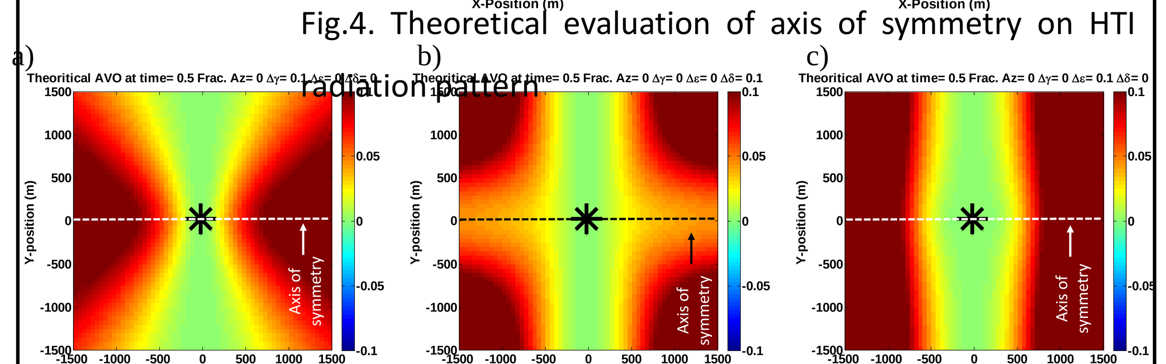

Fig.5. Theoretical evaluation of anisotropic parameters on HTI radiation pattern

Radiation patterns in VTI anisotropic models

- The analysis are based on AVO/AZ approximations of Rüger (1997)
- As shown in Figure 6, the VTI model is characterized by angle of incident only (Independent from azimuth)
- Theoretical formulation of AVO/AZ are evaluated in Figure 6.

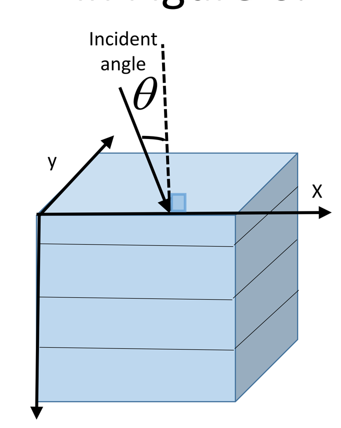

Fig.6. VTI model

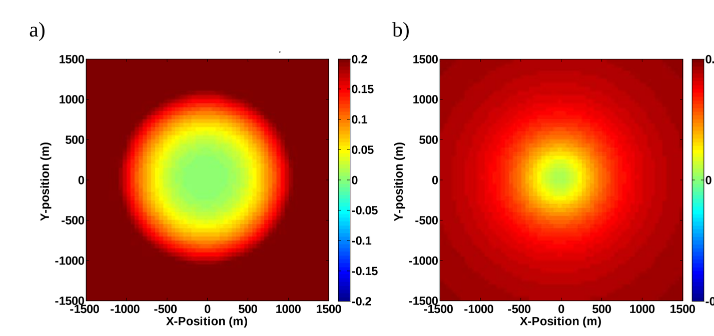

Fig.7. Theoretical evaluation of anisotropic parameters on VTI radiation pattern

Effect of acquisition constrain on AVO/AZ

- For numerical evaluation HTI and VTI models, we use 3D anisotropic Kirchhoff modeling and PSTM.
- Table 1 and table 2 shows the parameters used for acquisition and migration.
- Modeling/Migration#2 with isotropic and HTI#1, HTI#2 and HTI#3 are considered in this section.
- The result of modeling is shown in Figure.
- In next section we compare the same HTI scenarios with Modeling/Migration#1.

Table.1. Acquisition, modeling and migration parameters

	Length in x	Length in y	Length in t	dx_{bin}	dy_{bin}	dx_{rec}	dy_{rec}
Modeling #2	3000 m	3000 m	1.5 s	50 m	50 m	100 m	100 m
Migration#2	3000 m	3000 m	0.5 s	50 m	50 m	100 m	100 m
Modeling #1	3000 m	3000 m	1.5 s	50 m	50 m	25 m	375 m
Migration#1	3000 m	3000 m	0.5 s	12.5 m	12.5 m	25 m	375 m

Table.2. Isotropic and anisotropic parameters used for numerical evaluations

Modeling	$\frac{\Delta v_P}{\bar{v}_P}$	$\frac{\Delta Z}{\bar{Z}}$	$\frac{\Delta G}{\bar{G}}$	$\Delta\delta^{(V)}$	$\Delta\varepsilon^{(V)}$	$\Delta\gamma$	$\phi_{ref}{}^{o}$
Isotropic	0.1	0.1	0.1	0	0	0	NA
HTI #1	0.1	0.1	0.1	0.1	0.1	0.1	0°
HTI #2	0.1	0.1	0.1	0.1	0.1	0.1	45°
HTI #3	0.1	0.1	0.1	0.1	0.1	0.1	90°
HTI #4	0.0	0.0	0.0	0.1	0.0	0.0	0°
HTI #5	0.0	0.0	0.0	0.0	0.1	0.0	0°
HTI #6	0.0	0.0	0.0	0.0	0.0	0.1	0°
VTI #1	0.0	0.0	0.0	0.1	0.0	NA	NA
VTI #2	0.0	0.0	0.0	0.0	0.1	NA	NA

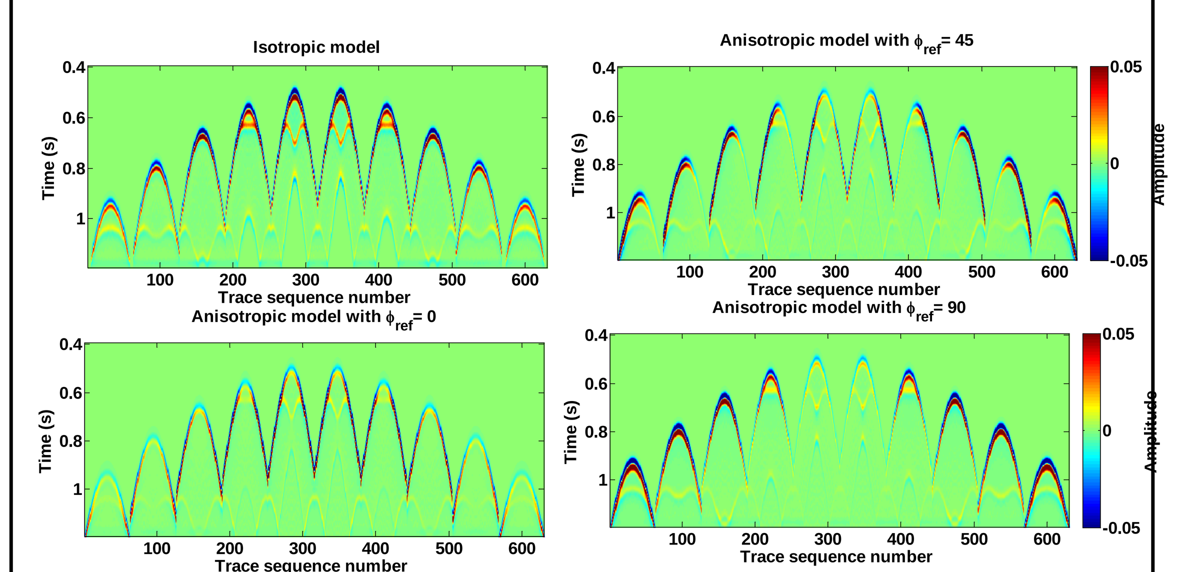

Fig.8. 3D modeled data for a) isotropic, b) the Modeling#1 and HTI#1, c) the Modeling#1 and HTI#2, d) the Modeling#1 and HTI#3 .

Migration and AVO/AZ patterns

- The time slice of PSTM in acquisition scenarios are compared in Figures 9-10.
- As seen, once the data are migrated, the acquisition fold can only cover half of source receiver offsets. Also compared to Figure 9, the dense sampling scenario improves the amplitude balance of migration.

Figure 9 represent the effect of azimuth of axis of symmetry on HTI medium. The blue dots in Figure 8a represent laid out geophones.

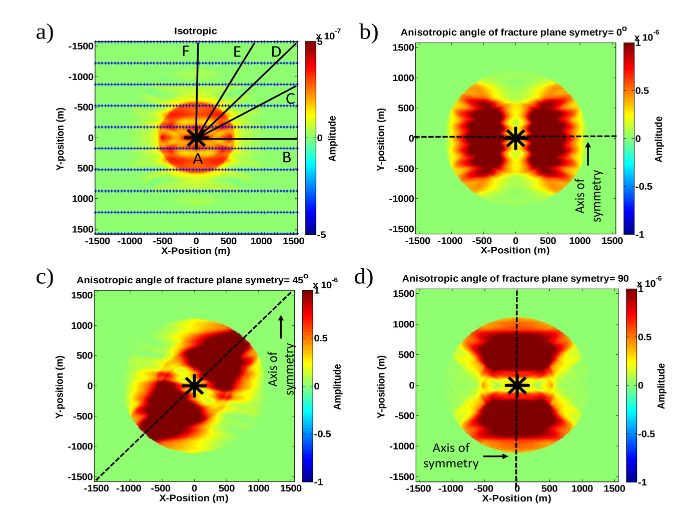

Fig.10. Azimuthal variation in Modeling/Migration#1 on HTI radiation pattern

Figure 10 represent the effect of azimuth of axis of symmetry on HTI medium.
Figure 11 represent the radiation pattern of HTI parameters under its acquisition constrains. As expected in Figure 12, their AVO/AZ least square fitting is improved.

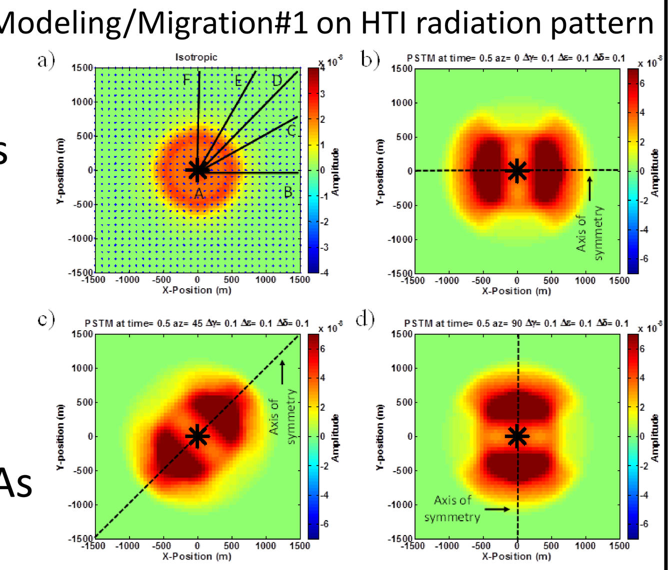

Fig.10. Azimuthal variation in Modeling/Migration#2 on HTI radiation pattern

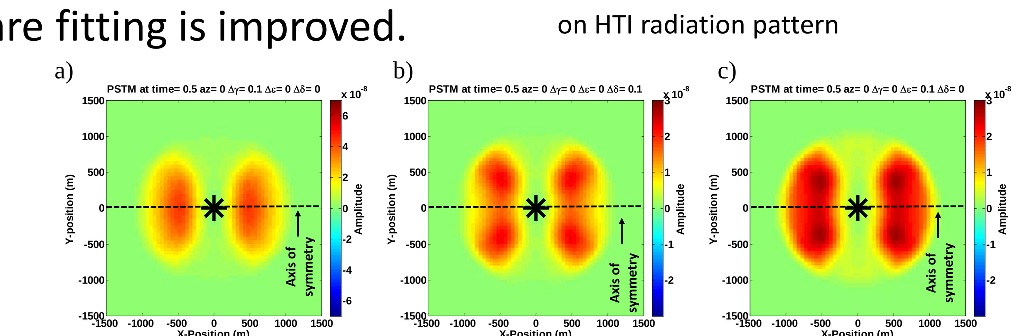

Fig.11. Modeling/Migration#2 on HTI radiation pattern

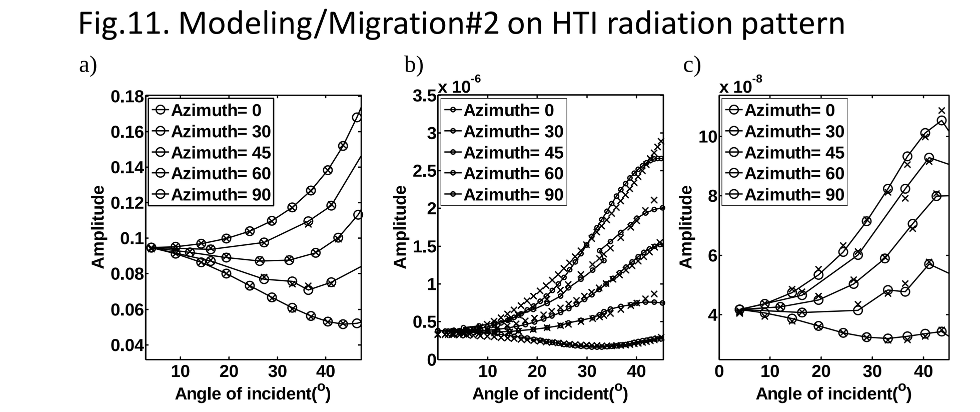

Fig.12. The AVO/AZ curves and the least square fitting values for scenarios of a) theoretical, b) Modeling/Migration#1 and c) Modeling/Migration#2

As shown in Figure 13, our analysis shows the artefact of acquisition in inversion of VTI model.

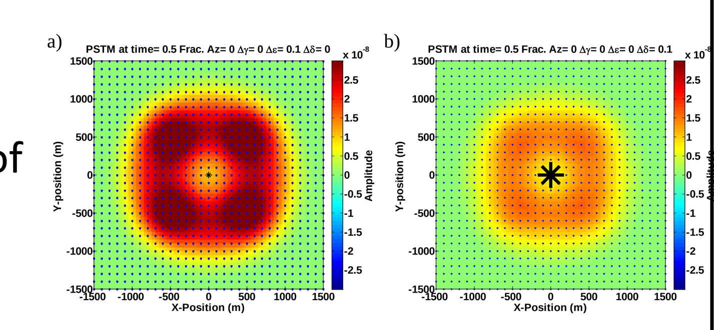

Fig.13. Modeling/Migration#2 on a) VTI#1 and b)VTI#2

Conclusions

Practical implementation of theoretical AVO/AZ requires forward modeling and migration based on true acquisition geometry. We discussed the effects of spatial sampling in the performance migration and AVO/AZ inversion.