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Efficient imaging aperture criterion for reduction of computational cost of TTI RTM

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SUMMARY

Seismic migration is an important step in conversion of seismic data into a subsurface image. The cost of the migration depends upon the choice of migration algorithm, dimensionality of space or time and the medium properties. There are range of migration methods exists today. Among all the approaches the two way wave equation based RTM (Reverse Time Migration) migration is found to be most accurate in terms of dealing with complexity of the medium. RTM complexity and cost increases as be go from isotropy to anisotropy medium. The wave equations invloved in solving a TTI (Tilted Transverse Isotropic) RTM are much more complex than the VTI (Vertically Transverse Isotropy) RTM or a ISO (Isotropic) RTM. Additionally, the parameter controlling the cost factor of individual shot migration is the imaging aperture. A good aperture is essential for accurately imaging subsurface features. In this paper we are demonstrating the implementation of 2D TTI RTM using different aperture criterion. We have studies the compute resource difference for various aperture methods and accuracy of TTI results using BP TTI model and field data.
Key words: Migration, RTM, TTI, Imaging, Aperture

INTRODUCTION

Seismic migration is a crucial step in transforming seismic data into a subsurface image, typically representing the final stage of the seismic data processing cycle. The complexity of migration largely depends on the chosen migration algorithm, the dimensionality of space or time, and the properties of the medium, such as isotropy or anisotropy. A variety of migration methods are available today. Among these, RTM (Baysal et al. (1983), Claerbout (1971)) based on the two-way wave equation is recognized for its accuracy in handling the complexities of the medium. The complexity of RTM increases when moving from isotropic to anisotropic media. The wave equations used in Tilted Transverse Isotropic (TTI) RTM are significantly more intricate than those in Vertically Transverse Isotropy (VTI) RTM or Isotropic (ISO) RTM.

Furthermore, the computational resources required for RTM vary based on the type of wave equations used, ranging from isotropic to TTI, and from two-dimensional to three-dimensional media. Another critical parameter in seismic migration is the imaging aperture, essential for effectively imaging subsurface features.This paper presents the implementation of 2D TTI RTM utilizing various aperture criteria. We examine the differences in computational resource requirements for different aperture methods and assess the accuracy of TTI results using the BP TTI model and field data.

TTI RTM

For TTI RTM implementation, a 2D constant density acoustic wave equation based formulations were used which are given from Equation 1 to Equation 4 (Fletcher et al. (2009)).

$$\frac{\partial^2 H}{\partial t^2} = v_{px}^2 \frac{\partial^2 H}{\partial \tilde{x}^2} + v_{pz} v_{pn} \frac{\partial^2 V}{\partial \tilde{z}^2} \tag{1}$$

$$\frac{\partial^2 V}{\partial t^2} = v_{pz} v_{pn} \frac{\partial^2 H}{\partial \tilde{x}^2} + v_{pz}^2 \frac{\partial^2 V}{\partial \tilde{z}^2} \tag{2}$$

$$\frac{\partial^2}{\partial \tilde{x}^2} = \cos^2\theta \frac{\partial^2}{\partial x^2} + \sin^2\theta \frac{\partial^2}{\partial z^2} + \sin 2\theta \frac{\partial^2}{\partial x \partial z} \tag{3}$$

$$\frac{\partial^2}{\partial \tilde{z}^2} = \sin^2\theta \frac{\partial^2}{\partial x^2} + \cos^2\theta \frac{\partial^2}{\partial z^2} - \sin 2\theta \frac{\partial^2}{\partial x \partial z} \tag{4}$$

Where, H and V are horizontal and vertical stresses, v_{pz} is vertical P-wave velocity, $v_{px} = v_{pz}\sqrt{1+2\epsilon}$ is horizontal P-wave velocity, $v_{pn} = v_{pz}\sqrt{1+2\delta}$ is P-wave moveout velocity, ϵ and δ are Thompsen's anisotropic parameters, θ is the dip angle These equations are solved using Finite Difference (FD) approximation on a regular grid with second-order accuracy in time and fourth-order accuracy in space. The paramter models were discretized using a cartesian grid. Absorbing boundaries were used on all the boundaries (Pasalic and McGarry (2010)). The ricker source wavelet can be introduced during time marching stage at a specified source location in the medium. The RTM image of each shot is created by cross-correlation the forward and backward wavefield using the Equation 5 (Rastogi et al. (2022))

$$I_{cc}(x,z) = \sum_{s}\sum_{t} S_s(x,z,t)R_s(x,z,t) \tag{5}$$

Where, I_{cc} is the RTM image, S_s is source wave field, R_s is receiver wavefield, t is FD time step and (x, z) are grid points for a 2D medium. The individual shot gathers were processed for RTM artifacts and far energy muting before addition.

Imaging Aperture

Imaging aperture is the lateral extent of the velocity model which is considered for RTM for a particular shot geometry. The size of the sub velocity model can affect the computation time and resources such as memory/storage. It also govern the quality of imaging. Too less aperture will reduce the cost of imaging but may be insufficient for mapping in case of complex geology and vice versa. In this paper we are experimenting the following imaging aperture criterion for its effect on the computational resources and accuracy of the results using TTI RTM.

a) Shot centric aperture: In this approach we keep the shot position as the center of the imaging aperture. Imaging aperture can take maximum length which is the twice of the maximum offset.

b) Fold centric aperture: In this approach we keep the imaging aperture center at the CMP fold center of the receiver spread.

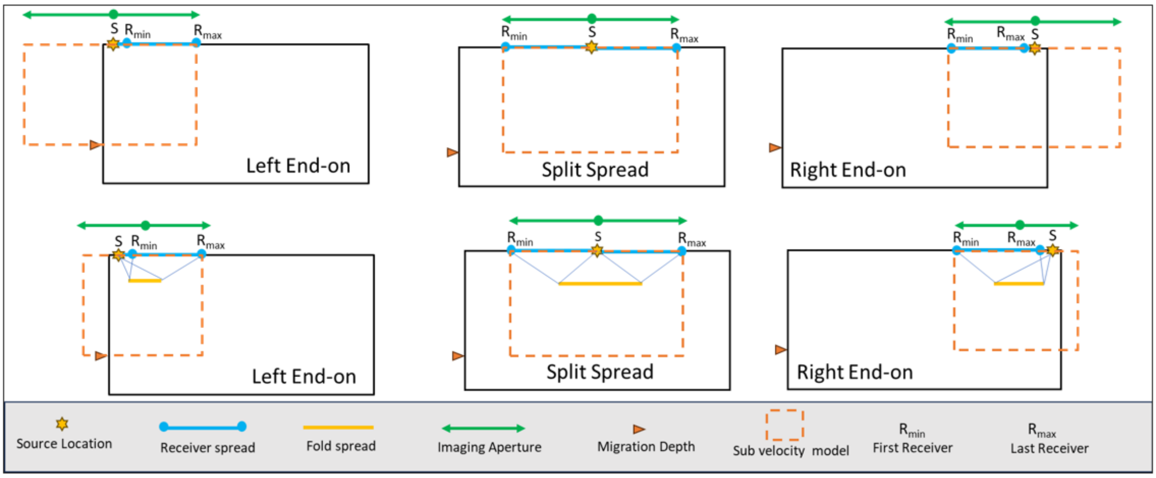


Figure 1. Schematic representation of imaging aperture for various geometries (a) shot centric with maximum offset in the first row, and (b) fold centric with maximum offset in the second row

EXPERIMENTS, RESULTS AND DISCUSSION

HPC System

For this research, we utilized the PARAM Porul cluster [1], which features 2 X Intel Xeon Cascadelake 8268, 24 cores, 2.9 Ghz, processors per node, 192GB memory and 480 GB SSD. Each node boasts 192 GB of memory, and the total storage capacity of the system is 1 PiB, based on a Parallel File System (PFS). For our experiments we used in-house developed program, "SeisRTM," which offers 2D & 3D modeling and RTM capabilities. The software suite is written in C and C++. For parallelization, we employed MPI APIs, OpenMP, and OpenACC.

TTI Modeling

The developed application was tested for its modeling capabilities using a homogeneous medium with different combinations of ϵ, δ and θ parameters along with a constant velocity of 3000 m/s. In this experiment we have used the Ricker wavelet of 40 Hz maximum frequency. The source was kept at the center of a 1000×1000 grid model with 10 m grid spacing. The modeling was run for 1.8 sec. Figure 2 (a-c) shows the snapshots for various combination of the anisotropy parameters recorded at 0.6 sec. Figure 2 (d-f), we can see three cases of snapshots for various combination of anisotropy parameters which represents ISO, VTI and TTI in homogeneous media.

[1] https://nsmindia.in/node/202

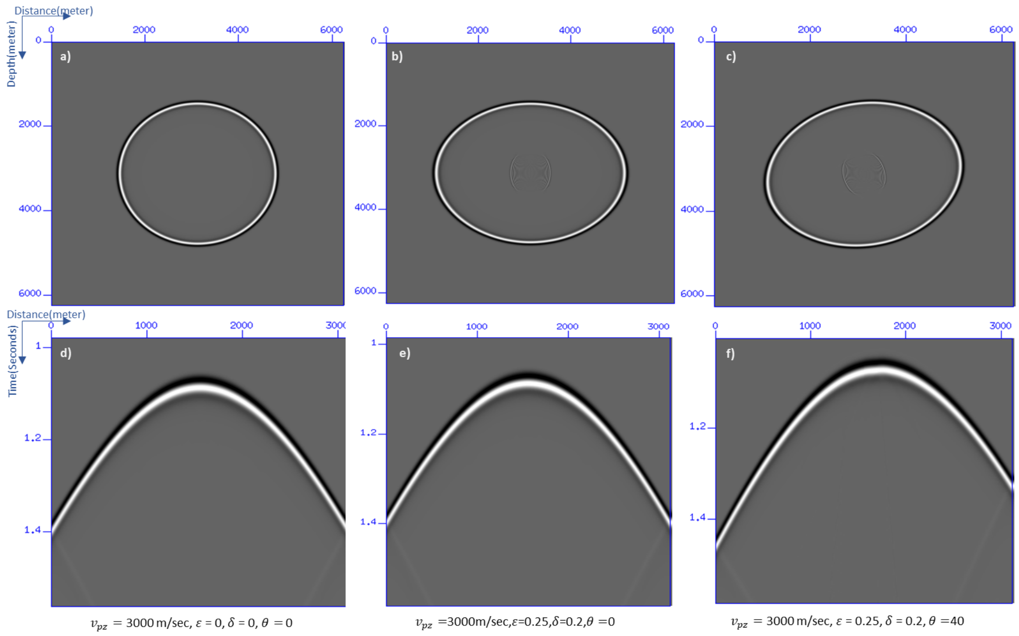


Figure 2. Snapshot generated with different anisotropy model parameters representing (a) Isotropy (b) Vertically Transverse Isotropy (c) Tilted Transverse Isotropy in homogeneous media. (d-f) are corresponding shot gathers generated using 2D TTI modeling

TTI RTM

The migration capabilities of the application were tested using BP TTI model and field data. These test cases were run using different imaging apertures for comparison of their outcome in terms of accuracy and compute time as well as resources.

BP TTI model

Figure 3 (a-d) shows the BP TTI model parameters and Figure 3 (e) shows the data parameters for RTM [2]. Figure 4 (a-b) shows the outcome of shot centric imaging aperture and fold centric imaging aperture. The RTM execution time for 500 shots along with its memory requirement are given in Figure 4 (c). The memory/storage required for each shot gather is 28 GB for shot centric aperture with aperture distance 10025 m and 24 GB for fold centric aperture with aperture distance 8500 m. 1.16X memory/storage has been saved for each shot gather while running RTM using fold centric aperture technique. The compute times obtain for 500 shots on 12 CPU nodes with shot centric aperture is 8.86 hrs and 6.5 hrs for fold centric aperture in TTI RTM. The Fold centric aperture technique has reduced the compute time for RTM of 500 shots by 1.36X. The results of shot and fold centric aperture are also comparable.

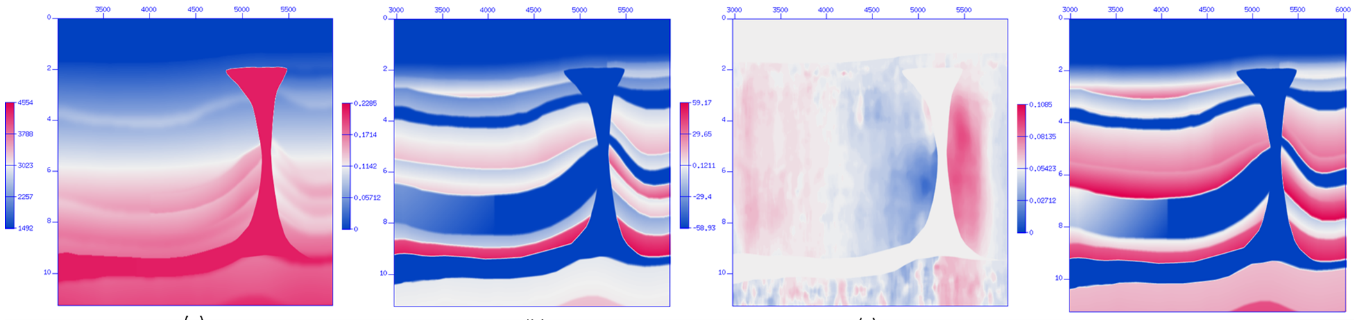
Real Field data

Figure 5 (a-d) shows the parameter models and Figure 5 (e) shows the data parameters for RTM. Figure 6 (a-b) shows the outcome of shot centric imaging aperture and fold centric imaging aperture. The RTM execution time for 500 shots along with its memory requirement are given in Figure 6 (c). The memory/storage required for each shot gather is 170 GB for shot centric aperture with aperture distance 8300 m and 129 GB for fold centric aperture with aperture distance 6220 m. 1.37X memory/storage has been saved for each shot gather while running RTM with fold centric aperture technique. The compute time obtain for 500 shots on 15 CPU nodes with shot centric aperture is 9 hrs. and 6.8 hrs for fold centric aperture in TTI RTM. The fold centric aperture technique has reduced the compute time for RTM of 500 shots by 1.32X. The results of shot and fold centric aperture are comparable.

CONCLUSIONS

We studied the cost of migrating seismic data using TTI media using various type of aperture criterion. We demonstrated two types of imaging aperture namely; shot, fold centric and compared their outcome in terms of memory, runtime and accuracy. The in-house developed TTI modeling capabilities were showcased using simple homogeneous test case. The TTI RTM was demonstrated using BP TTI and Field data. We have got reduction in runtime as well as memory requirement with equivalent accuracy in the fold centric imaging aperture in both the cases. In the near future we will conduct experiments with imaging aperture using 3D RTM.

[2] https://wiki.seg.org/wiki/2007_BP_Anisotropic_Velocity_Benchmark

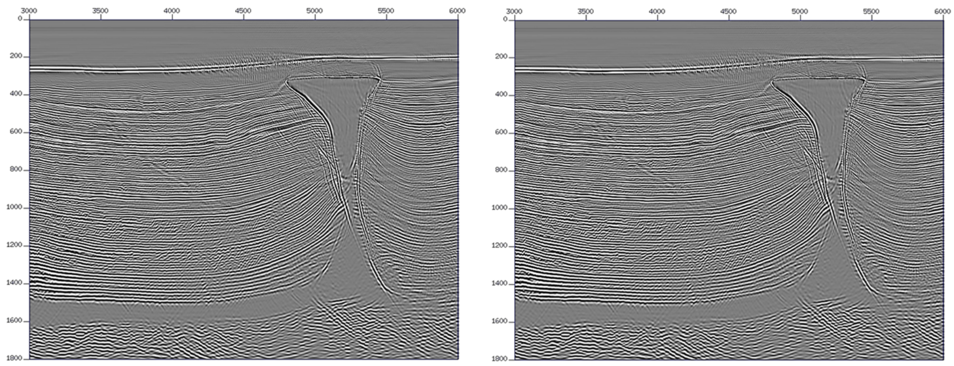


(a) (b) (c) (d)

Data Parameters					
Shot spacing	50m	Receiver spacing	12.5m	No. of shots	500
Geometry type	End-on	Receivers per shot	801	Min offset	12.5m
Max offset	10025m	Frequency	25Hz		

(e)

Figure 3. BP Model Parameters (a) V_{pz} (b) ϵ (c) θ (d) δ (e) Data Parameters

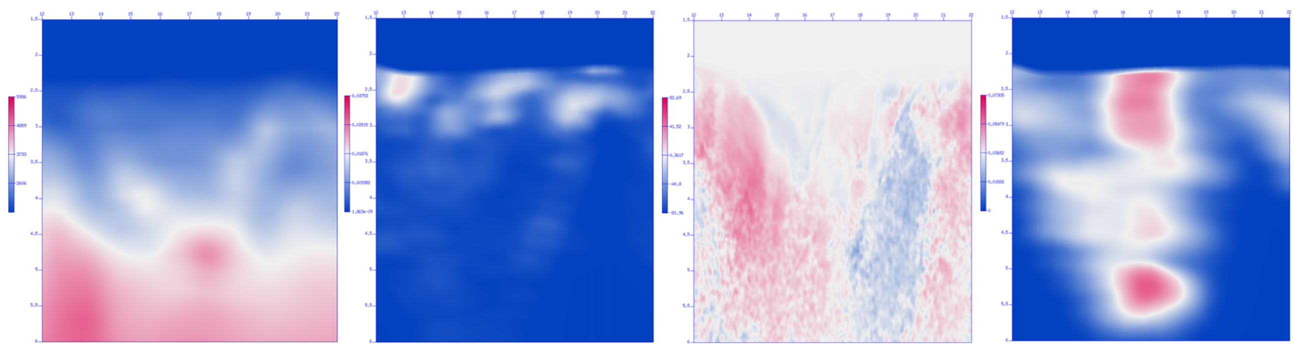


(a) (b)

	Aperture Technique	
	Shot Centric	Fold Centric
Aperture Distance	10025 m	8500 m
Memory Required	28.92 GB	24.70 GB
Execution Time	8.86 Hrs.	6.53 Hrs.

(c)

Figure 4. BP TTI Model - RTM output with different technique (a) Shot Centric Imaging Aperture (b) Fold Centric Imaging Aperture (c) Computational Requirment

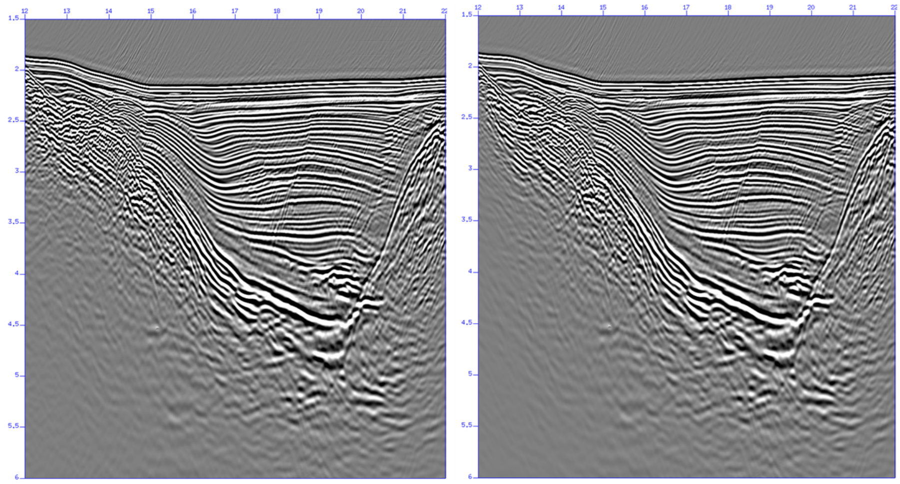


(a) (b) (c) (d)

Data Parameters					
Shot spacing	50m	Receiver spacing	12.5m	No. of shots	500
Geometry type	End-on	Receivers per shot	656	Min offset	112.5m
Max offset	8300m	Frequency	25Hz		

(e)

Figure 5. Real Field Model Parameters (a) V_{pz} (b) ϵ (c) θ (d) δ (e) Data Parameters



(a) (b)

	Aperture Technique	
	Shot Centric	Fold Centric
Aperture Distance	8300 m	6220 m
Memory Required	170.23 GB	129.52 GB
Execution Time	9 Hrs.	6.8 Hrs.

(c)

Figure 6. Real Field Data - RTM output with different technique (a) Shot Centric Imaging Aperture (b) Fold Centric Imaging Aperture (c) Computational Requirment

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