Polynomial amplitude versus azimuth inversion in horizontally transverse isotropic media, as tested on fractured coal seams in the Surat Basin

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Introduction

A new technique of amplitude versus azimuth (AVAZ) seismic inversion in horizontally transverse isotropic (HTI) media is presented and is an effective method of characterizing anisotropic variation within individual reflectors as well as characterizing fractures. The method calculates more interpretable anisotropic components than currently available techniques. This method is then extended to AVO and a work flow to calculate Thompson (1986) anisotropy parameters is presented. Less error is incorporated in the inverted parameters compared with the elliptic method and there are fewer independent terms in the inversion than what is in the Fourier method.

Data from an open file 3D wide azimuth seismic survey in the Surat Basin were inverted to demonstrate the effectiveness of these techniques. Seismic amplitudes from six azimuthal stacks were extracted over two horizons and inverted around a well where full wave sonic and density logs were acquired. For both horizons, the error between the inverted anisotropy parameters from seismic and the inverted anisotropy parameters from wire line logs was found to be less than 5% for both horizons.

Inversion Procedure

The P- wave reflectivity equation in HTI media can be written in terms of its isotropic, R_P^{iso} and anisotropic components which can then be decomposed into the elliptic, $E(i)$ and anelliptic, $F(i)$ ansotropic components with the polynomial

$$R_P^{HTI}(i,\phi) = R_P^{iso}(i) + E(i)\cos^2\phi + F(i)\cos^4\phi$$

where

$$E(i) = [\Delta\delta^{(V)} + 2(\frac{2\bar{\beta}}{\bar{\alpha}})^2\Delta\gamma + \frac{1}{2}\Delta\delta^{(V)}\tan^2 i]\sin^2 i$$

and

$$F(i) = \frac{1}{2}[\Delta\varepsilon^{(V)} - \Delta\delta^{(V)}]\sin^2 i \tan^2 i$$

(Rüger, 2001).This parametrization allows for simple inversion of the anisotropy by recognizing the parabolic nature of the above equations. The anisotropic response over all azimuths, ϕ can be represented in an unbiased manner using the integral of the anisotropic response, R_P^{ani} over all azimuths, $\phi \in \Phi$ with

$$Total \quad Anisotropy = \int_\Phi R_P^{ani}(i,\phi)d\phi = \frac{\pi}{8}[3E(i) + 4F(i)].$$

The ratio between the total amount of anisotropy and the isotropic response is therefore

$$\frac{3E(i) + 4F(i)}{8R_P^{iso}(i)}$$

and can be used as a simple method of tying inverted seismic to wells where the anisotropy parameters in HTI media are known. This parameter will be referred to as the Integrated Anisotropy.

This inversion algorithm requires an estimate of the azimuthal term, ϕ and contains four independent terms, two less than the Fourier method which contains six independent terms (Downton and Roure, 2015).

AVO Applications

This parametrization can be extended to AVO with the gradients

$$B^{iso} = \frac{1}{2}[\frac{\Delta\alpha}{\bar{\alpha}} - (\frac{2\bar{\beta}}{\bar{\alpha}})^2\frac{\Delta G}{\bar{G}} + \frac{\Delta\alpha}{\bar{\alpha}}\tan^2 i]$$

$$B_1^{ani} = \Delta\delta^{(V)} + 2(\frac{2\bar{\beta}}{\bar{\alpha}})^2\Delta\gamma + \frac{1}{2}\Delta\delta^{(V)}\tan^2 i = E(i)/\sin^2 i$$

$$B_2^{ani} = \frac{1}{2}[\Delta\varepsilon^{(V)} - \Delta\delta^{(V)}]\tan^2 i = F(i)/\sin^2 i$$

where B_1^{ani} and B_2^{ani} are the exact elliptic and anelliptic AVO gradients in HTI media.

The $\Delta\delta^{(V)}$ and $\Delta\gamma$ Thompsen (1986) parameters can be calculated by linearizing B_1^{ani}about $\tan^2 i$ such that $\Delta\delta^{(V)}$ is calculated from the gradient

$$dB_1^{ani}/d(\tan^2 i) = \Delta\delta^{(V)}/2.$$

$\Delta\gamma$ is calculated using

$$\Delta\gamma = \frac{B_1^{ani}|_{i=0} - \Delta\delta^{(V)}}{2(\frac{2\bar{\beta}}{\bar{\alpha}})^2},$$

and $\Delta\varepsilon^{(V)}$ using

$$\Delta\varepsilon^{(V)} = 2\frac{dB_2^{ani}}{d(\tan^2 i)} + \Delta\delta^{(V)}.$$

B_1^{ani} is a precise representation of the elliptic component of the anisotropy under the weak anisotropy assumption and is therefore not conformable to the Fourier or elliptic AVO gradients (Rüger, 2001; Downton and Roure, 2015).

Results

The inversion procedure was applied to an open file 3D wide azimuth seismic survey in the Surat Basin. Attribute maps with dimensions of 3763m by 3763m are presented which show some of these attributes.

Figures 1 and 2 are the full stack and isotropic, R_P^{iso} responses respectively. Figures 3 and 4 are the elliptic, $E(i)$ and anelliptic, $F(i)$ components of anisotropy respectively. Figure 5 is the Anisotropic response integrated about all azimuths and Figure 6 is the ellipticity which was calculated in a manner conformable to Rüger (2001).

Table 1 compares the Integrated Anisotropy between the inverted seismic and a well in this region which was inverted by Kremor and Amrouch (2017).

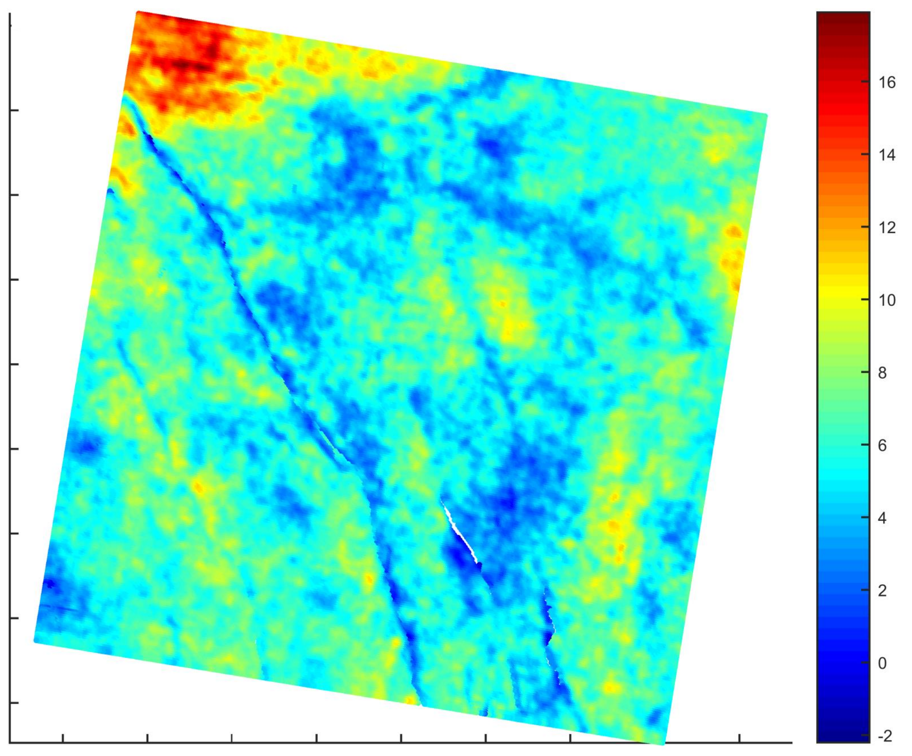

Figure 1 – Full Stack Reflectivity

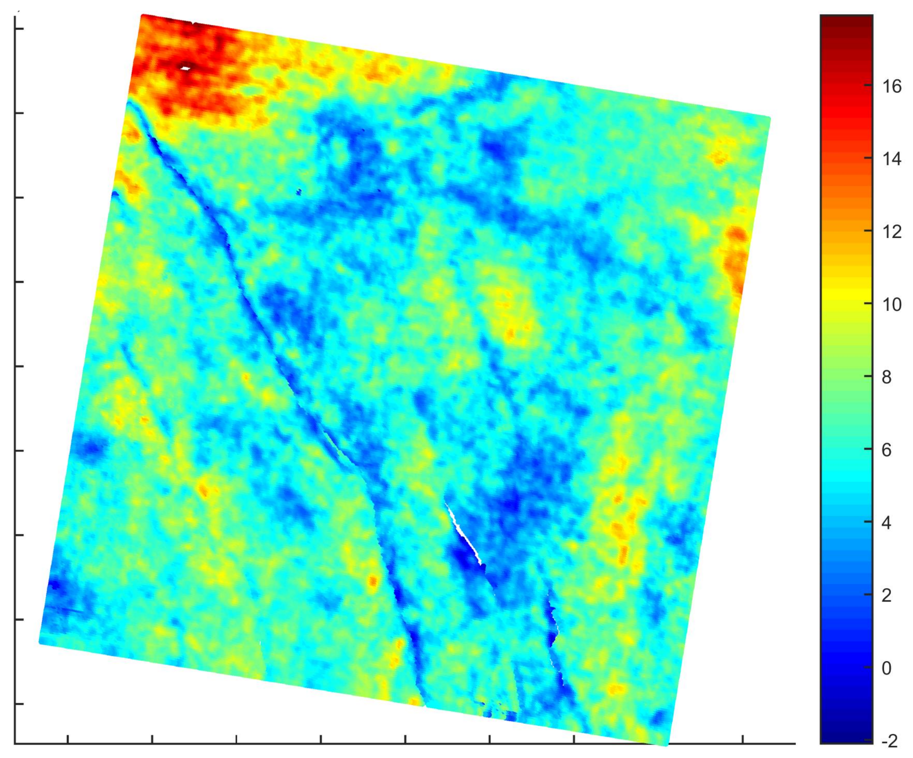

Figure 2 – Isotropic Reflectivity

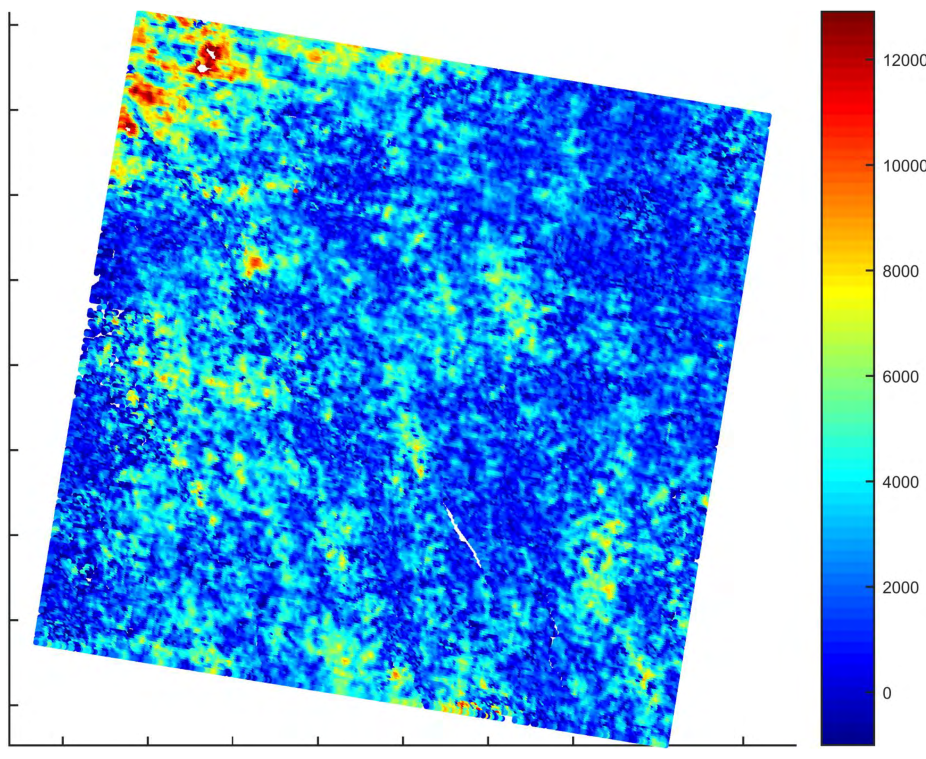

Figure 3 – Elliptic, $E(i)$ Reflectivity

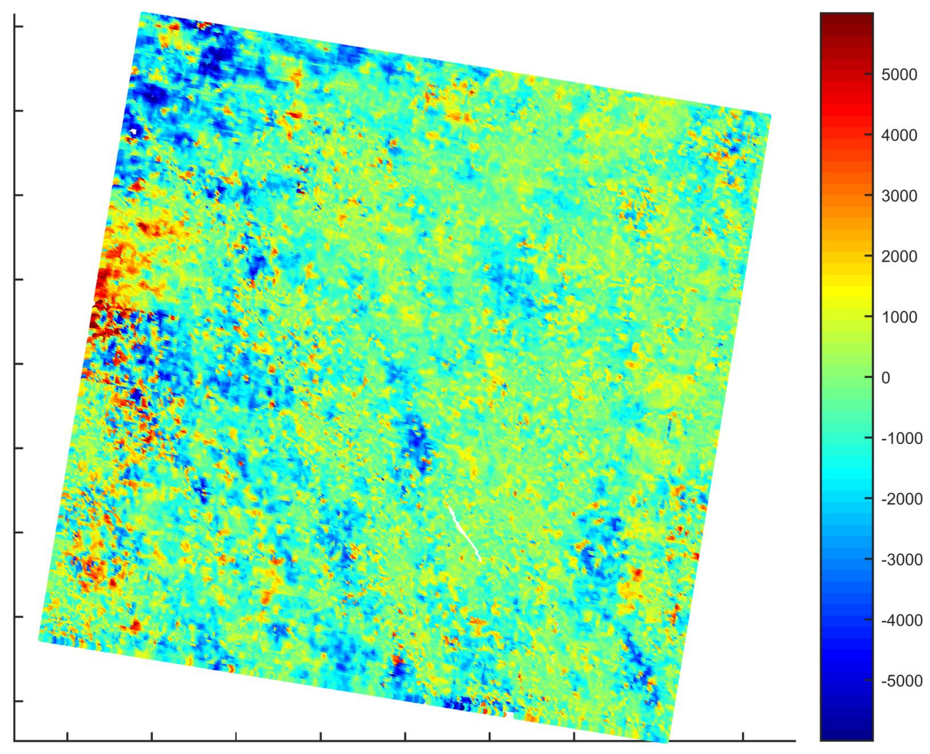

Figure 4 – Anelliptic, $F(i)$ Reflectivity

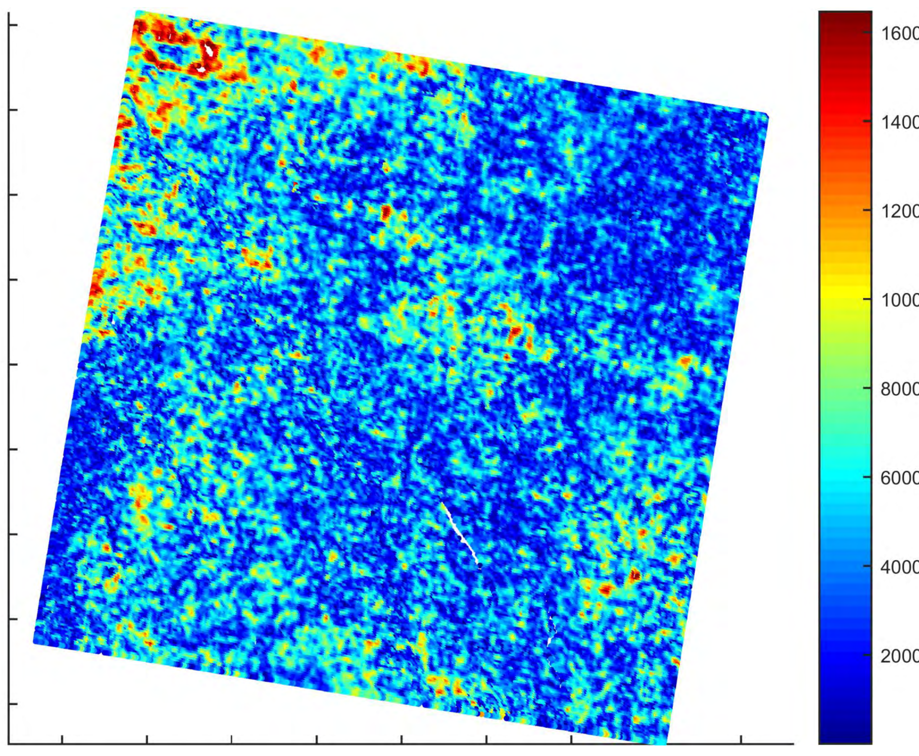

Figure 5 – Total Anisotropy

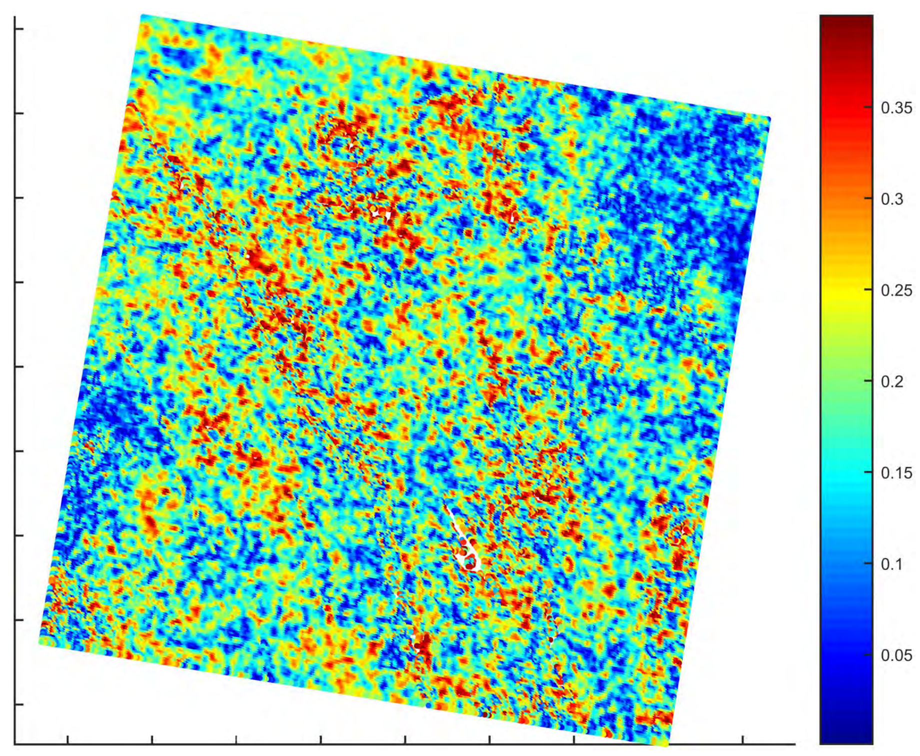

Figure 6 – Ellipticity as per Rüger (2001)

Table 1 – Anisotropy from Inverted Seismic and From Wire Line Logs (Kremor and Amrouch, 2017)

	Walloon Coal Measures	Taroom Coal Measures
Integrated Anisotropy from Seismic	0.1258	0.2656
Integrated Anisotropy from Wire Line Logs	0.1296	0.2545
Error (%)	**2.93**	**4.36**

Conclusion

An AVAZ method of characterizing the anisotropic response of HTI media has been presented using terms which hold interpretable meaning. AVO gradients for this technique have been defined and a workflow to calculate Thompson (1986) parameters has been presented. These methods were then compared with inverted anisotropy parameters from well logs and were found to be accurate to within 5% on two horizons.

This method affords the geoscientist more interpretable attributes than what currently available AVAZ methods for HTI media can produce and will be useful in fractured and unconventional reservoirs. Furthermore, the application of this method over the elliptic method will result in a reduced amount of error incorporated into the inverted parameters and is a simpler approach than the Fourier method.

References

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Rüger, A. (2001). 'Reflection Coefficients and Azimuthal AVO Analysis in Anisotropic Media.' (Society of Exploration Geophysicists: Tusla.)

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