Influence of seismic anisotropy in NMO correction

Silva, M. B. C.[1]; Rodriguez, C.[2] and Fontoura, S. A. B.[1]
[1] GTEP PUC-Rio
[2] Petrobras/UN-Rio/ATP-Ro/Res

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Abstract

This aim of this work is to investigate the errors generated when VTI anisotropy is not considered for normal moveout correction of seismic data. Synthetic data (with different degrees of anisotropy) were processed and the errors on layer depth and NMO velocity were quantified. The results show that NMO velocity is more sensible to δ than ε (as expected) and that water depth and anisotropic layer thickness did not influence the velocity error in any of the tests.

Introduction

The evidences that the earth crust has anisotropic characteristics regarding wave propagation are known since the early second half of the 20th century (White & Sengbush, 1953 and Backus, 1962). However, for a long time, anisotropy was considered to be an academic issue even though differences between depth-migration results and real data were evident in some instances. Major contribution in the 80's and 90's have moved anisotropy to the level of practical issues to be dealt with during seismic data processing and interpretation.

The NMO velocity is important because, besides being fundamental on migration and stacking, in some cases it is the only velocity information of the data and the first guess for inversion and time-to-depth conversion.

In this paper, we evaluate the differences in NMO velocity when an anisotropic rock is processed considering isotropic behavior. For this purpose, synthetic data were generated varying the Thomsen's parameters, ε and δ, for the anisotropic layer, using a seismic modeling package based on ray tracing. Velocity analyses were carried out in these data as if the material were isotropic. The errors in NMO velocities and depth for anisotropic models were compared with the reference case ($\varepsilon=\delta=0$).

Method

Figure 1 shows a simple offshore geological scenario with an anisotropic rock layer resting on an isotropic layer. Layer thickness and rock properties for the scenario displayed in figure 1 are shown in table 1. Synthetic seismograms were generated using the seismic modeling package *anray* (Anray, 2000) that can take into account the anisotropic properties of rocks. The seismic data were processed as if the rocks were isotropic and the errors obtained in stacking velocity (that can be used as RMS velocity or NMO velocity) were quantified for different degrees of anisotropy and also for different layer thickness. All data were processed independently and V_{RMS} were then compared among each other.

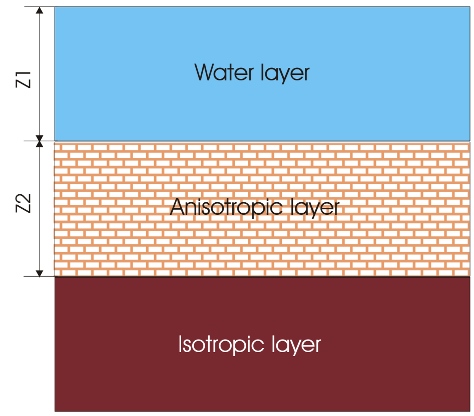

Figure 1: Geologic model used for experiments.

The reference model, or "background" (according to Hudson (1980)), is the isotropic model. All other models are anisotropic versions of this reference. It can be seen in the following table the range used for layer thickness and anisotropy intensity in all simulation:

Layer	Z_l (m)	V_P (km/s)	V_S (km/s)	Density (g/cm^3)	ε	δ
1	500/1500	1.5	0	1.01	0	0
2	500/1500	2.8	1.2	1.8	0/+0.2	-0.2/+0.2
3	500	2.2	1	2.2	0	0

δ was simulated for values between -0.2 and +0.2 (with 0.05 step), but ε was simulated only for positive values between 0 and +0.2 (with 0.05 step, resulting in 45 simulations for each Model). According to Tsvankin & Grechka (2005), on VTI medium ε is always positive, but δ can be negative or positive.

Three models with different layer thickness were built (135 simulations for all models):

- Model1: $z_1 = 500m$ and $z_2 = 1000m$
- Model2: $z_1 = 1000m$ and $z_2 = 1000m$
- Model3: $z_1 = 1000m$ and $z_2 = 1500m$

The acquisition scheme for the synthetic data is shown in Figure 2. The receiver interval was 25m and 50 shots were generated with a 25m shot interval. The modeling program, Anray, has a limitation regarding the possible offset since it accepts a maximum of 100 receivers. This maximum offset is considered small for anisotropic examples, but it will be used in our tests knowing that we are using the isotropic assumption for processing.

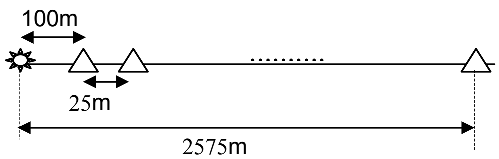

Figure 2: Acquisition geometry for the synthetic data.

The data processing algorithm was developed in Matlab® and the sequence used can be described as:

1. Sorting the data into CMP (where all shot and receiver coordinates were obtained by the midpoint between shot and receiver);
2. Preparing the data to semblance analysis by choosing some CMPs, apply constant velocity moveout using the hyperbolic equation (Sheriff & Geldart, 1995) and pick the most appropriate value;
3. After choosing the best time-variant velocity function, apply NMO correction;
4. Picking the mute (by graphic visualization) to clean the NMO corrected data;
5. Stacking the NMO corrected and clean data; and
6. Time-to-depth conversion of the processed section, using the velocity function obtained during processing (velocity analysis).

All the processed data were compared together (Figure 3) to verify the difference between the isotropic case and the anisotropic case processed with the isotropic assumption. All error measures are simple percentage error where the reference value is the isotropic case.

Results

After the data from the three models were processed, the error in the NMO velocity was calculated by:

$$E_{rel} = \frac{EX - M}{EX} \tag{1}$$

where the exact value (*EX*) is the velocity from the isotropic model and the measured value (*M*) is the velocity from the anisotropic models.

The results for the processing can be observed in the following pictures: the difference between the velocity functions for all anisotropic data processed with isotropic assumption (Figure 3) and the difference in depth if these velocity functions were used to time-to-depth convert the data (Figure 4).

Figures 3 and 4 have the same color definition for each curve: the blue lines plot the events for isotropic case; yellow for ε=0.2 and δ=0, red ε=0.2 and δ=0.05 (solid line) / δ=-0.05 (dashed line), magenta ε=0.2 and δ=0.1(solid line) / δ=-0.1 (dashed line), green ε=0.2 and δ=0.15(solid line) / δ=-0.15 (dashed line) and black ε=0.2 and δ=0.2(solid line) / δ=-0.2 (dashed line). At Figure 4, only results for positive δ are shown (all dashed lines were suppressed for simplification).

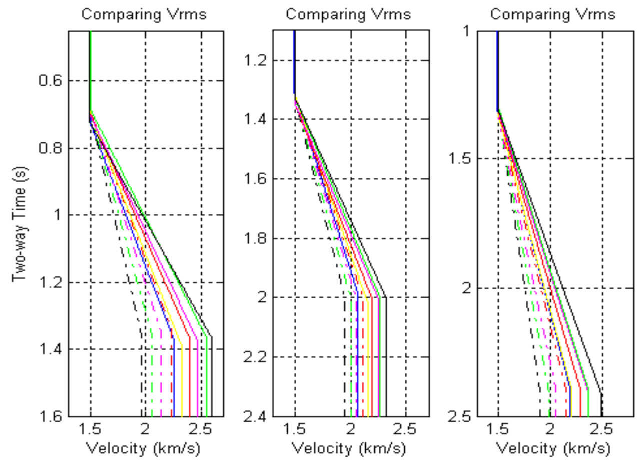

Figure 3: Stacking velocity function for ε=0.2 and $-0.2 \le \delta \le +0.2$. Results for Model1 (left), Model2 (center) and Model3 (right)

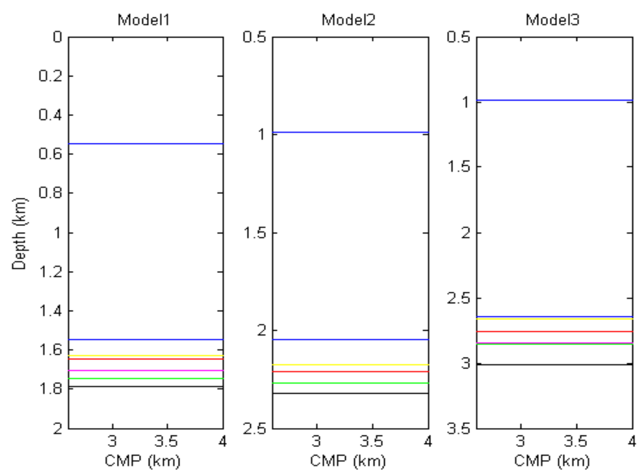

Figure 4: Depth differences obtained using wrong velocities to time-to-depth conversion. Results for Model1 (left), Model2 (center) and Model3 (right)

In Figure 4, for all positive δ, the reflector depth can be interpreted as deeper than their correct positions (as δ increases), and this difference can achieve almost 400m (for Model3). For the case of negative δ (not shown here), the reflector depth is interpreted as shallower then its correct position with the same difference of almost 400m (for Model3).

After all velocity functions were obtained by semblance analysis, the velocity relative errors were calculated. These errors achieve almost $\pm 15\%$ when $\delta = \pm 0.2$.

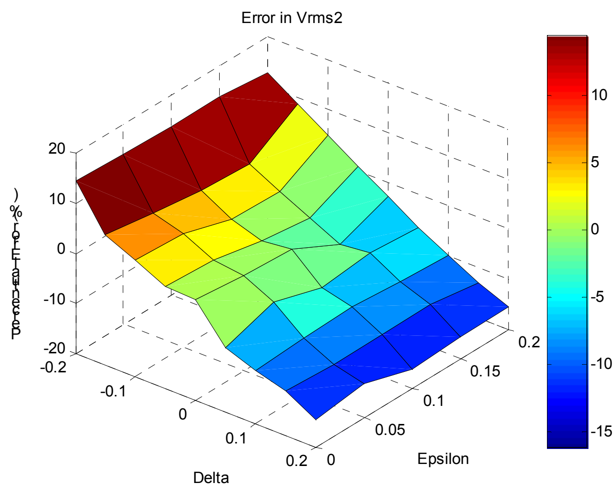

Figure 5: View of error in V_{RMS} for Model1.

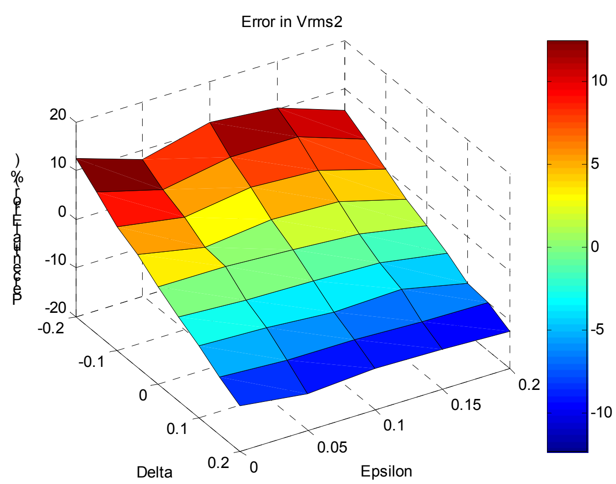

Figure 6: View of error in V_{RMS} for Model2.

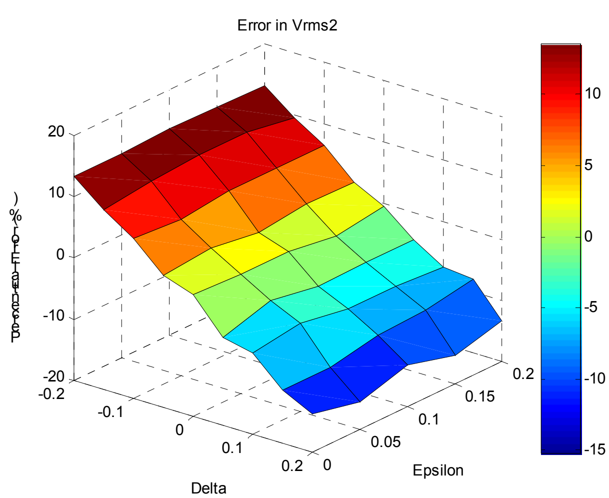

Figure 7: View of error in V_{RMS} for Model3.

On the 3D graphics of Figures 5, 6 and 7, it can be seen that δ influences much more velocity errors than ε. If a specific δ is chosen in any of the 3D graphics, one can see that the error in velocity for ε is almost constant.

These results can be understood from the definition of ε (Eq. (2)) and δ (Eq. (3)). As ε is the ratio between the vertical and horizontal P-wave velocities and δ is related to P-wave velocity variation in angles close to the vertical, and the seismic section is obtained on small angle propagation (close to vertical), δ will influence more on RMS (or NMO) velocity than ε.

$$\varepsilon \equiv \frac{V_P{}^2(90^o) - V_P{}^2(0^o)}{2V_P{}^2(0^o)} \qquad (2)$$

$$\delta \equiv \frac{V_{NMO}{}^2 - V_P{}^2(0^o)}{2V_P{}^2(0^o)} \qquad (3)$$

where $V_P(0^0)$ is the P-wave velocity in vertical direction and $V_P(90^0)$ is the P-wave velocity in horizontal direction in one anisotropic layer.

In Figures 8 and 9 it can be seen that the thickness of both isotropic and anisotropic layers do not influence on the velocity error, only ε and δ. The three models were plot together and apart from small processing errors (present due to a manual velocity picking), the errors in velocity are the same for both ε and δ. One can see that for a specific δ value, the velocity error is constant for any ε. This result is also explained by Eq. (2) and (3), where both ε and δ have no dependence of layer depth.

Conclusions

The exercise presented in this paper aimed to verify and quantify the influence of ignoring anisotropy in velocity analysis. For that, some synthetic data were generated (each one with different values of anisotropic parameters and layer thickness) by numerical modeling.

The results show that δ parameter influences more the error on NMO velocity than ε, as expected. Velocities errors caused by $|\delta| \approx 0.2$ were close to 15%. It was also verified that the velocity errors were not influenced by neither water depth nor anisotropic layer thickness, but only the anisotropic parameters.

Acknowledgments

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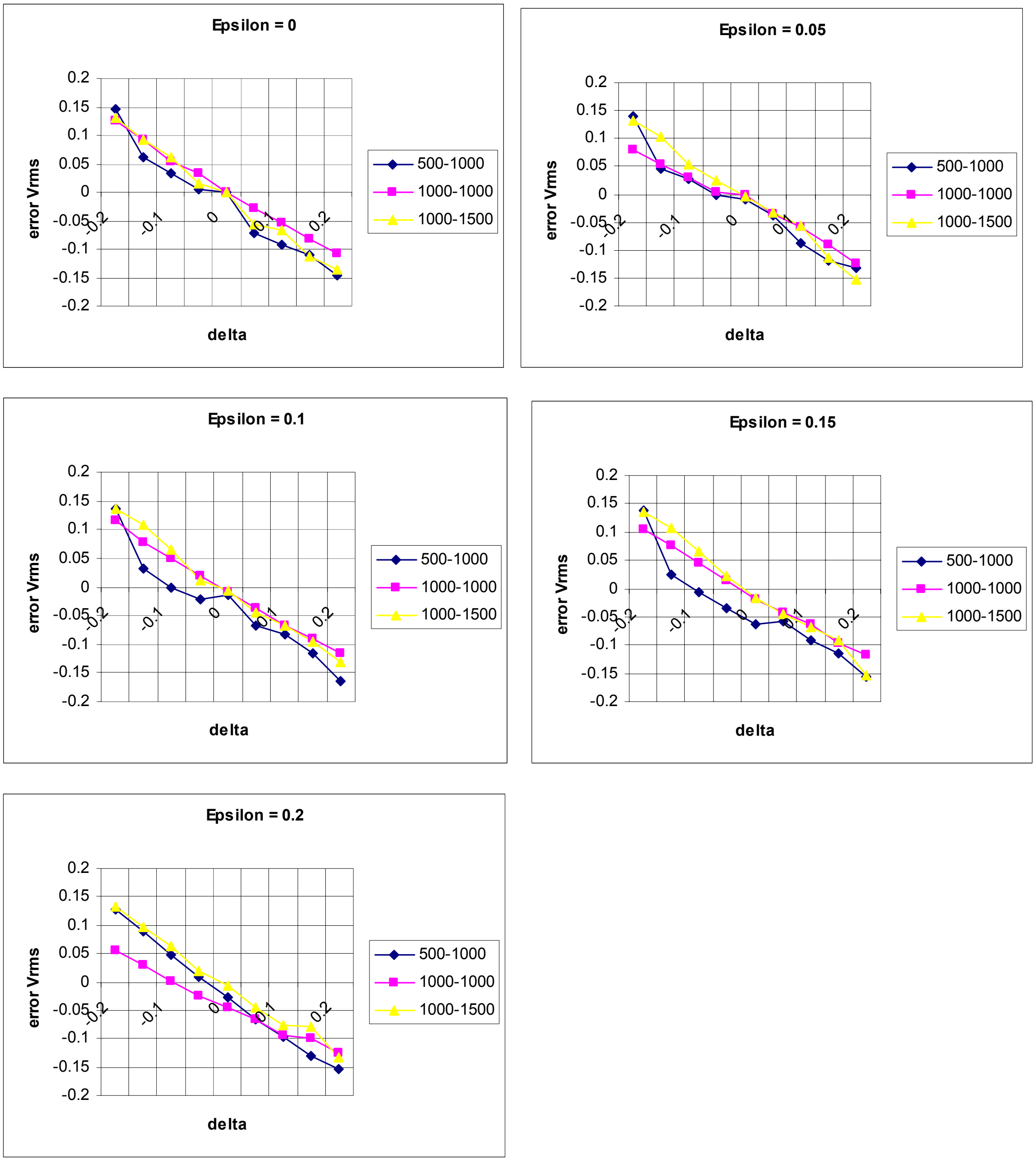

Figure 8: Comparison of different velocities errors with different ε and layers (water and anisotropic) thicknesses for the three models.

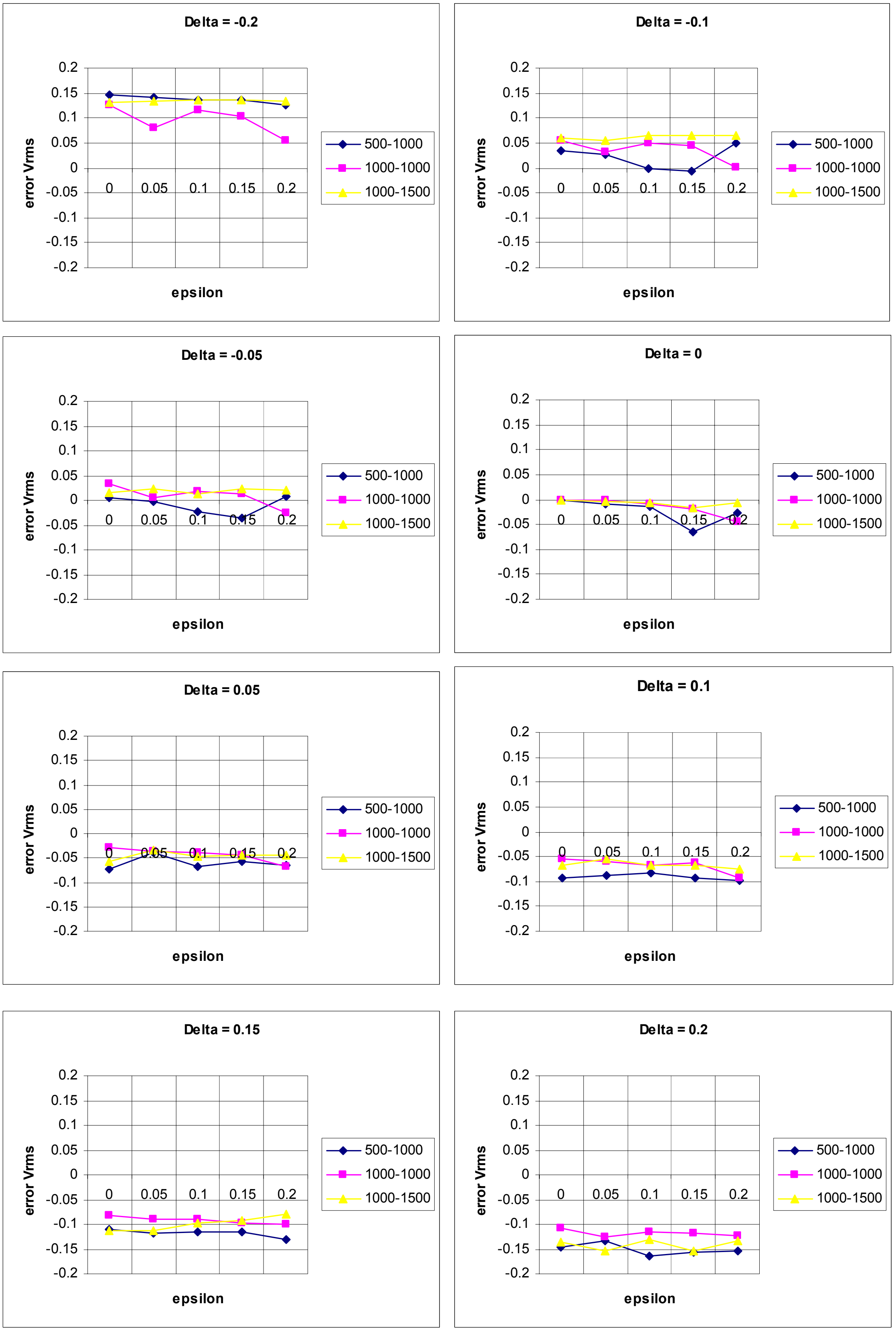

Figure 9: Comparison of different velocities errors with different δ and layers (water and anisotropic) thicknesses for the three models.