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The influence of multiples and imaging approximations on focusing-effect AVA detection and removal

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ABSTRACT

Focusing-effect AVA (FEAVA) consists of anomalous amplitudes due to transmission effects. In multiple-free synthetic datasets, whether simple or complex, the focusing is removed by migration with the correct velocity and an operator adjoint to that used in modeling. In multiple-affected synthetic datasets, migration with the correct velocity but with an operator less accurate than that used in modeling is only partially sucessful in removing FEAVA. There are numerical experiments which can distinguish whether this is due to the presence of multiples, to lack of imaging operator accuracy, or to lack of imaging-modeling adjointness.

INTRODUCTION

While propagating through velocity lenses, seismic wavefields focus and defocus, causing variations in recorded amplitudes. In the case of lateral velocity variations of a large spatial extent, reflected energy is redirected outside the survey aperture, causing illumination problems. Small lenses, producing small traveltime anomalies but rather visible amplitude focusing (Focusing-Effect AVA), do not bring about loss of information, making the recovery of velocity information from amplitudes and traveltimes feasible in principle.

Vlad and Biondi (2002) and Vlad (2002) show that Wave-Equation Migration Velocity Analysis (Biondi and Sava, 1999) is a highly suitable method for finding the FEAVA-causing velocity lenses. Vlad et al. (2003) show that for a simple synthetic dataset under optimal conditions, this method generates velocity models which eliminate FEAVA through migration with an operator of the same accuracy as the one used for modeling. Vlad (2004) also demonstrates a FEAVA detector on the same synthetic dataset.

Simple controlled experiments, however, are only the first step in the testing of scientific hypotheses. In this paper I advance by testing the previously proposed methods on a significantly more complex synthetic dataset. I examine the behavior of FEAVA in the data domain and in the image domain, in a setting with and without heavy internal multiples contamination, in an image migrated just with the background velocity trend and with the correct velocity model (one and eight reference velocities), with high offset sampling and with sparse offset sampling. In particular, the purposes of the study are: 1. Determining the robustness of

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FEAVA detection with respect to multiples and imaging approximations; 2. Probing the degree of amplitude accuracy needed by a migration operator in order to eliminate FEAVA from the image; 3. Finding to what extent internal multiples can interfere with FEAVA removal through migration.

EXPERIMENT SETUP

The numerical experiment uses a highly realistic velocity model composed of stratigraphically plausible succession of reflectors superimposed over a linearly increasing background velocity. Figure 1 displays some properties of the velocity model. The velocity variations are

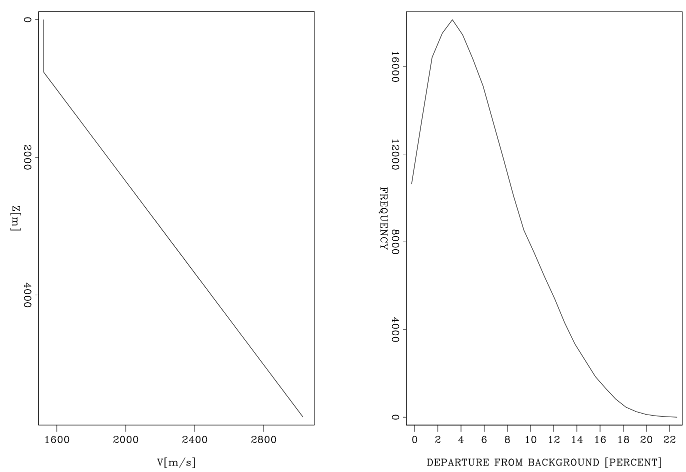

Figure 1: **Left:** Background velocity; **Right:** Histogram of velocity deviation from the background, in percentages, for a random number of samples in a certain region of the model. nick1-velomod [CR]

sufficiently abrupt to cause massive multiple internal reflections when modeled with a two-way propagation algorithm. Figure 2 shows both multiple-free data created with a one-way algorithm (split-step with three reference velocities) and multiple-affected data[2] created with a finite-difference algorithm. Vertical streaks of high-amplitude focusing are visible, especially in the multiple-free panel.

FEAVA IN THE IMAGE DOMAIN

In the absence of multiples

The top panel of Figure 3 displays the result of migrating the multiple-free data with the background velocity shown in the left panel of Figure 1. High-amplitude vertical streaks mark the presence of FEAVA. The FEAVA detector (Vlad, 2004) works by measuring the departure of AVA from the Shuey (1985) model. The output of the detector (bottom panel of Figure 3) highlights the AVA much more clearly than the stack. Migrating with the adjoint of the modeling operator (split-step, three reference velocities) eliminates the FEAVA from the image (Figure 4).

[2]courtesy of ChevronTexaco Corp.

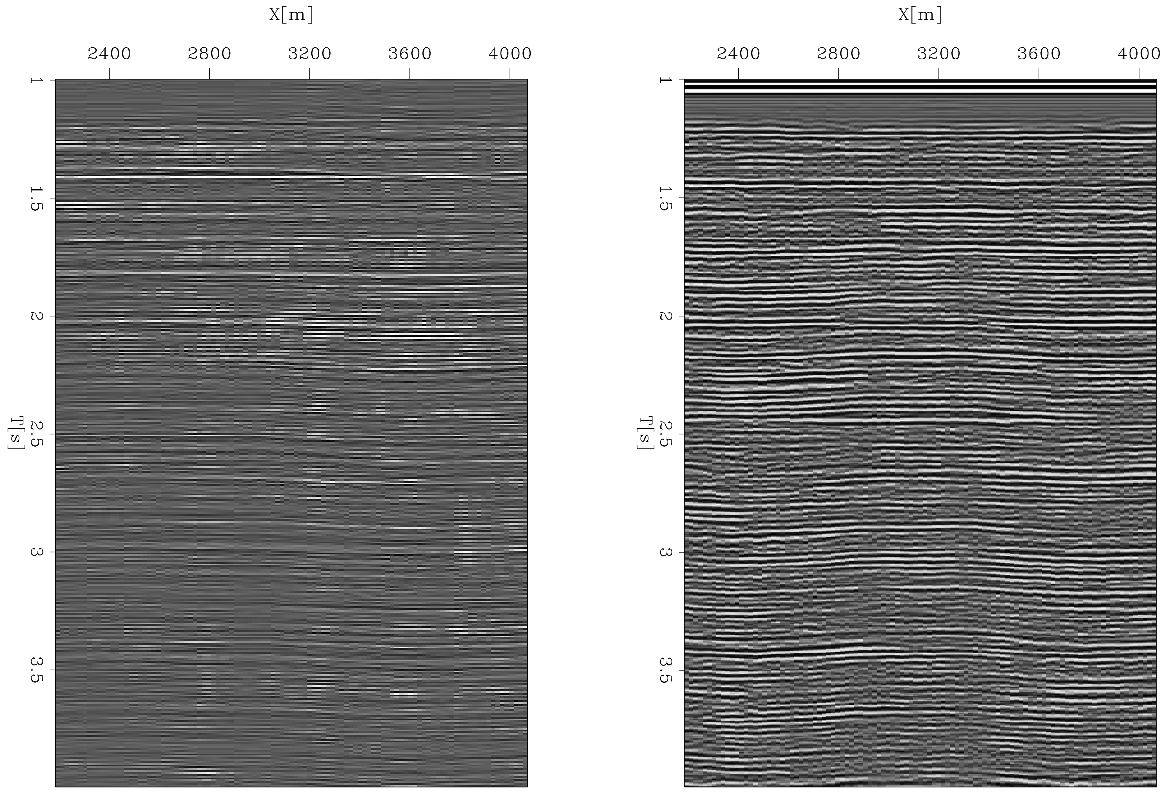

Figure 2: Zero-offset data. **Left:** without multiples; **Right:** with multiples. nick1-zoff [CR]

In the presence of multiples

High contrasts between layers in the velocity model cause a very large number of multiples to be generated. The result of migrating this multiple-affected dataset with the background trend from the left panel of Figure 1 is shown in the upper panels of Figure 5. FEAVA is indicated by a vertical path of high energy in the middle of the image and is clearly outlined by the FEAVA detector. Non-focused multiples depart from Shuey's approximation too, but the resulting FEAVA detector output is one order of magnitude smaller than that caused by actual focusing. The lower panels of Figure 5 show the results of migrating with the correct velocity model, albeit with a single reference velocity. The focusing is no longer visible in the image. The focusing-caused FEAVA detector output has fallen significantly, to the level of power of surrounding multiples. The two FEAVA outputs are displayed in the same intensity scale.

FEAVA was clearly reduced by migration, but not entirely eliminated. One natural question is whether significantly increasing the number of reference velocities in migration will improve the outcome. However, a migration with eight reference velocities which produced the upper panels of Figure 6, show that this is not the case for this type of stratigraphic play. The improvements are incremental, visible only by electronically displaying the two pictures in an animated sequence.

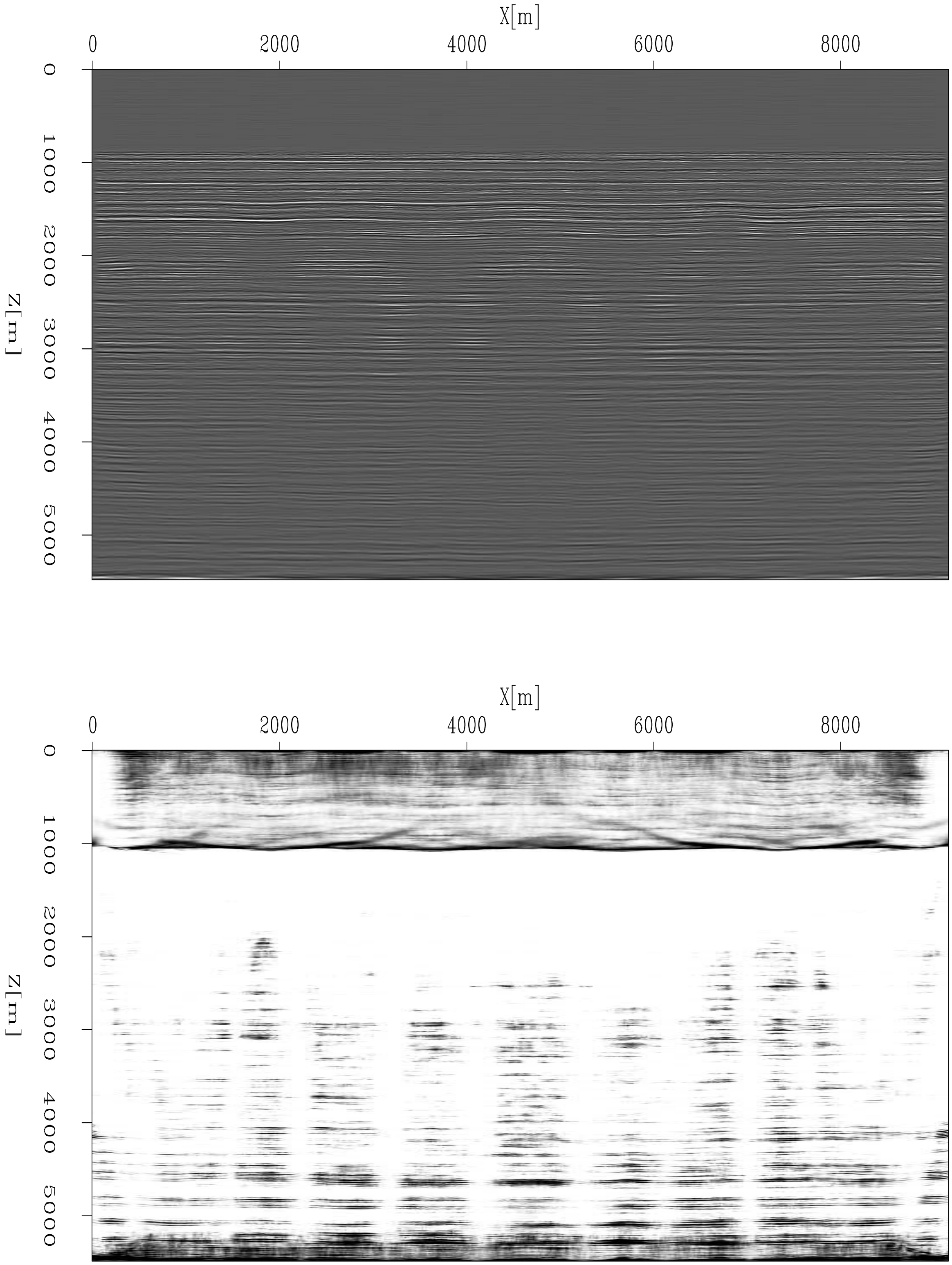

Figure 3: FEAVA is present after migrating the multiple-free data with the background velocity. **Top:** as higher-amplitude streaks in the stack (barely visible); **Bottom:** after applying the FEAVA detector. nick1-com_nomult_imag [CR]

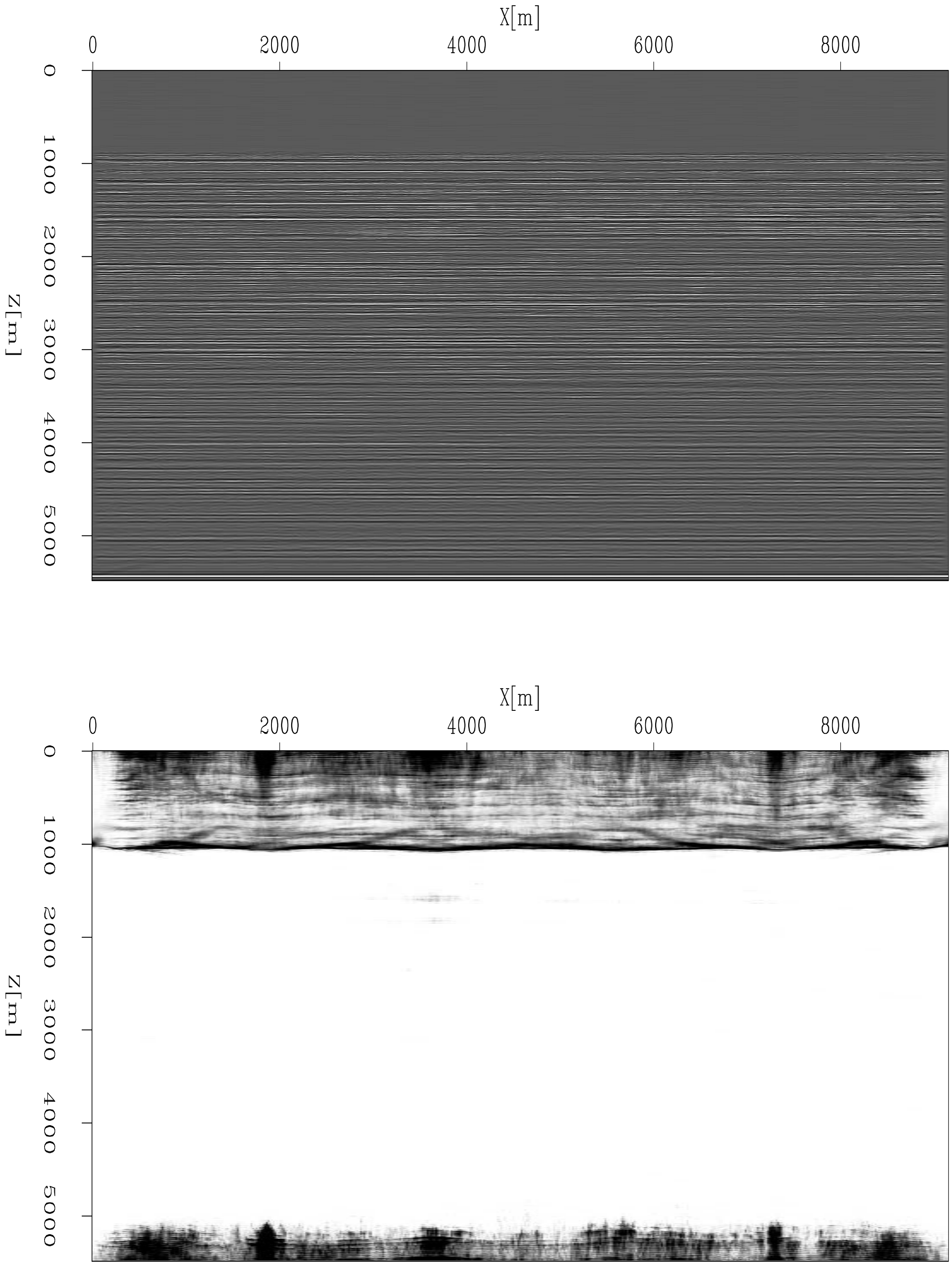

Figure 4: FEAVA disappears after migrating the multiple-free data with the correct velocity and the exact adjoint of the modeling operator. **Top:** Stack. **Bottom:** after applying the FEAVA detector. Compare with lower panel of Figure 3 nick1-com_nomult_imaC [CR]

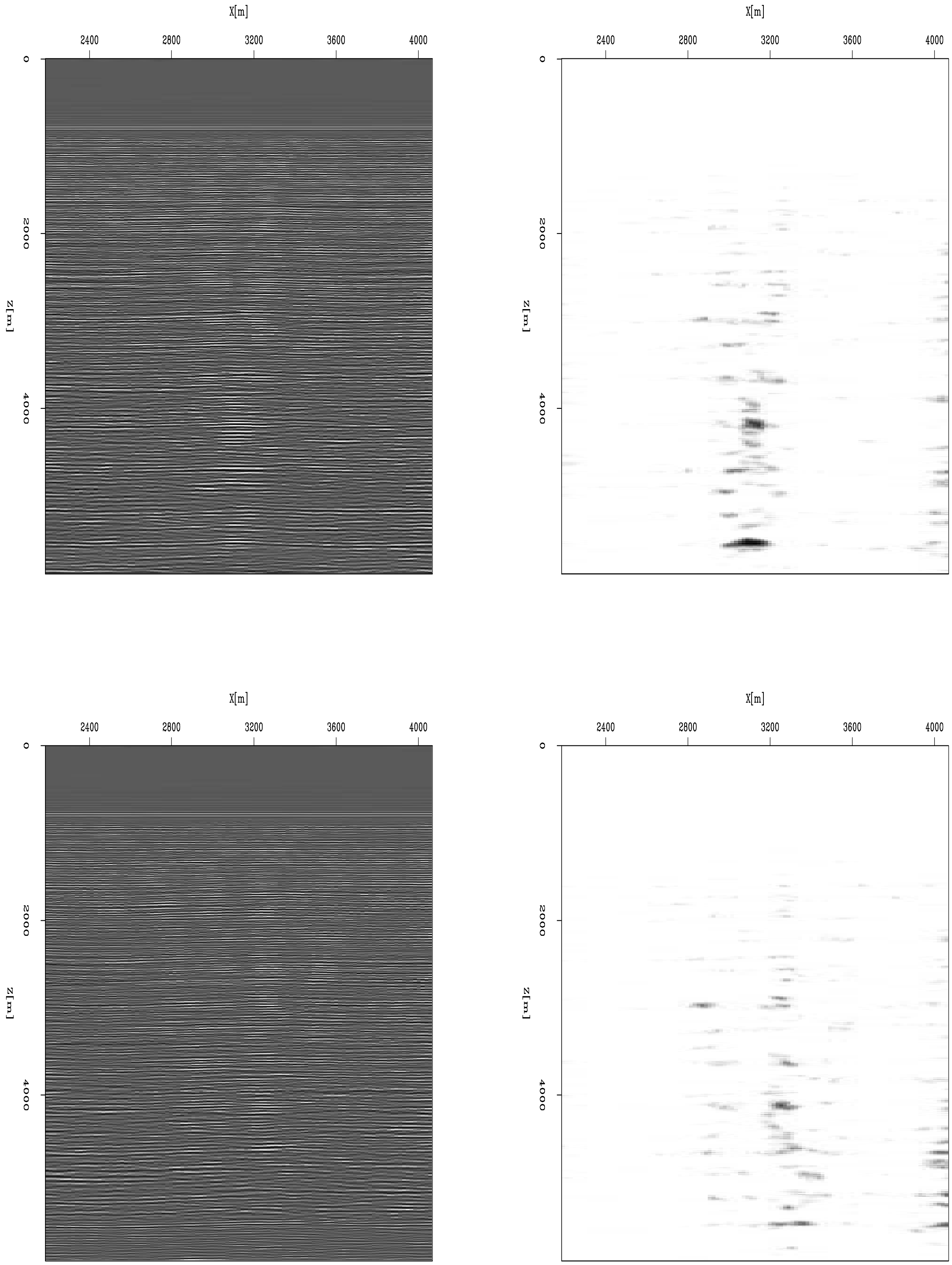

Figure 5: **Top-left:** image produced with the linear background velocity trend; **Top-right:** output of FEAVA detection applied after linear background velocity migration; **Bottom-left:** image produced with the correct velocity (split-step kernel with one reference velocity); **Bottom-right:** output of FEAVA detection applied after split-step migration with the correct model, one reference velocity. FEAVA detector outputs in the same color scale, for comparison. nick1-bg-refvel1 [CR]

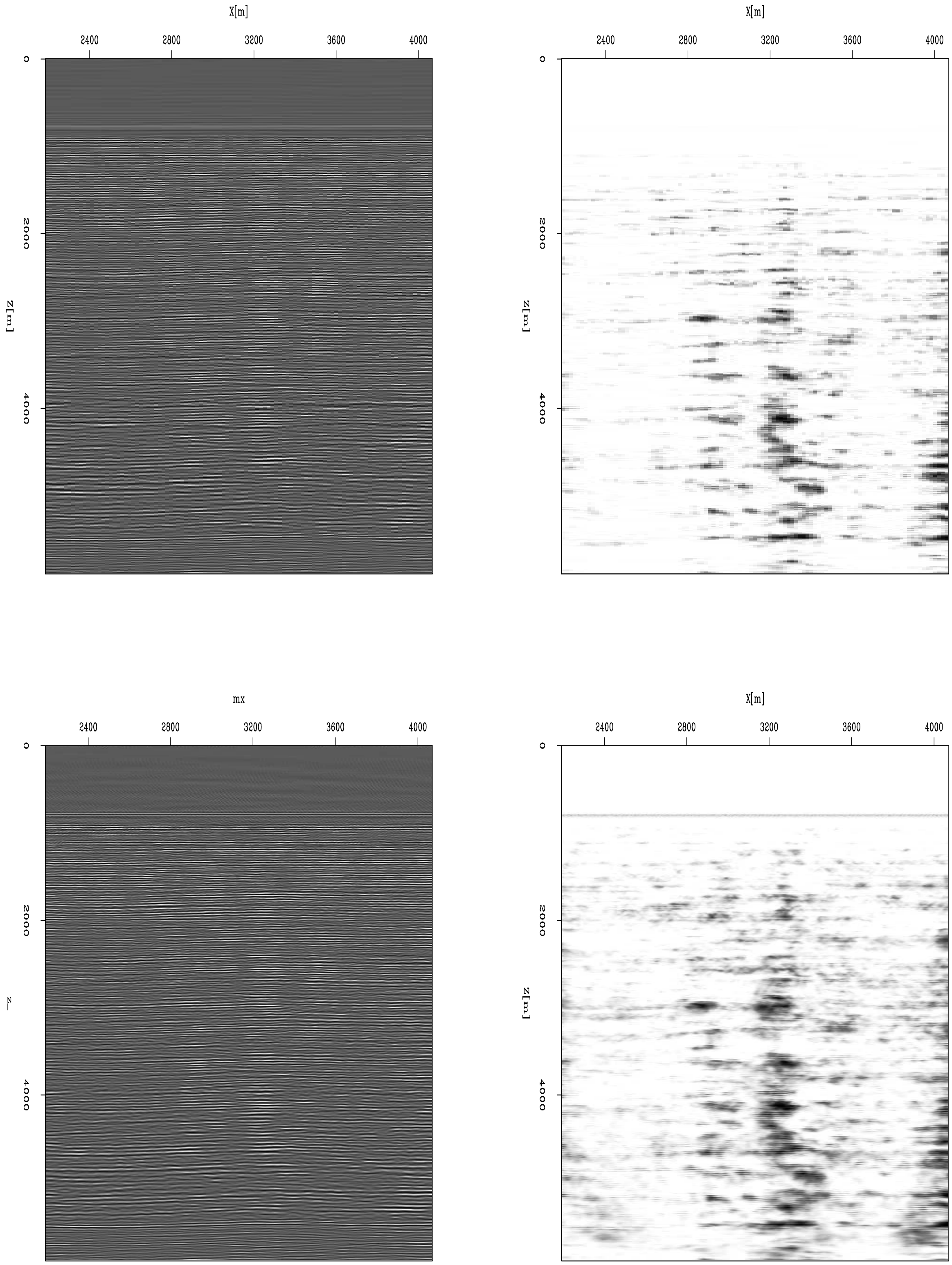

Figure 6: **Top-left:** image produced with the correct velocity (split-step kernel, eight reference velocities); **Top-right:** output of FEAVA detection applied after migration with the correct velocity (eight reference velocities); **Bottom-left:** image produced with the correct velocity (split-step kernel with one reference velocity) on dense data; **Bottom-right:** output of FEAVA detection applied after split-step migration with the correct model, one reference velocity on dense data. For detail enhancement, FEAVA detector outputs are not in the same color scale. nick1-refvel8-infill [CR]

Another potential limitation stems from the fact that, due to the combination of depth/offset sampling (Sava and Biondi, 2001), the range of angles into which offsets can be reliably transformed was limited to 15°, while the FEAVO detector works up to 30°. Would energy from greater angles improve the situation? The bottom panels of Figure 6 are produced with an offset sampling four times smaller than before, resulting in reliable transformations from offset to angle up to 45°. This does not bring improvements either. On the contrary, multiples, highly curved at large angles, create more noise in the FEAVA detector output. The extra smoothness comes from having decreased the midpoint sampling by a factor of four.

CONCLUSIONS

Lateral velocity deviations as small as three percent from the background can cause visible focusing. The FEAVA detector performs well both in the presence and in the absence of multiples. FEAVA removal by migration works when the migration operator is the adjoint of the modeling one and when no multiples are present. When internal multiples are present and imaging is performed with an algorithm of a lower order than the one used for modeling, FEAVA is removed only partially by migration. This is most likely caused by multiples not being defocused by a migration with the velocity of the primary reflections, regardless of the order of the algorithm. To verify this conjecture, one would need to model with an amplitude-preserving two-way algorithm two similarly complex datasets – one multiple-free and one multiple-affected, and then migrate each of them with the operator adjoint to the one used in modeling. If the conjecture is true, FEAVA will be removed completely from the multiple-free dataset, but only partially from the multiple-affected one. I also conjecture that, for a synthetic dataset, FEAVA removal is possible if the algorithm used for migration has the same accuracy or greater than the one used for modeling, and that exact adjointness of migration and modeling operators is not important. To verify this I will need to image with a higher-order algorithm a multiple-free dataset generated with a lower-order algorithm. I plan to verify these assertions in the near future.

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REFERENCES

Biondi, B., and Sava, P., 1999, Wave-equation migration velocity analysis: SEP–**100**, 11–34.

Sava, P., and Biondi, B., 2001, Amplitude-preserved wave-equation migration: SEP–**108**, 1–26.

Shuey, R. T., 1985, A simplification of the Zoeppritz equations: Geophysics, **50**, no. 4, 609–614.

Vlad, I., and Biondi, B., 2002, Velocity estimation for seismic data exhibiting focusing-effect AVO: SEP–**111**, 107–123.

Vlad, I., Biondi, B., and Sava, P., 2003, Velocity estimation for seismic data exhibiting focusing-effect AVO (Part 3): SEP–**114**, 101–109.

Vlad, I., 2002, Velocity estimation for seismic data exhibiting focusing-effect AVO (Part 2): SEP–**112**, 47–64.

Vlad, I., 2004, Velocity estimation for seismic data exhibiting focusing-effect AVO (Part 4): SEP–**115**, 265–272.