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Joint Tomography with OBN and WAZ Data

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SUMMARY

We present a joint tomography flow for ocean bottom node (OBN) and streamer wide azimuth data in deep water Gulf of Mexico. This tomography method uses surface offset gathers from surveys with different shot and receiver datums together for joint tomography. By incorporating both OBN and streamer data in tomography, the aperture and coarse sampling limitations of OBN can be overcome, and OBN strengths of full azimuth coverage, better low frequency, longer offsets, and higher signal-to-noise ratio of OBN data can be exploited. The result is better velocity model building.

Introduction

Ocean bottom node (OBN) data have many advantages over streamer data in both 3D and 4D seismic imaging in deep water Gulf of Mexico. OBN surveys provide full-azimuth coverage, long offsets, and better low frequencies and higher signal-to-noise ratio (S/N) than streamer data (Beal 2014; Beaudoin and Ross 2007; Boelle et al. 2010). However, processing OBN data can be challenging. Due to the high cost of equipment, deployment and acquisition of nodes, most OBN surveys are limited in size and node density. A typical deep water GOM OBN survey may be ~200 km^2 with approximately 1000–1500 nodes spaced 300–400 m apart. Although OBN-only model building results in a reasonable velocity update near the center of the node coverage, the areal constraints limit our ability to build an accurate model, especially for subsalt structures.

Early strategies to address the problem use pre-existing streamer data and conventional model building techniques (Stophin et al. 2008). Although straightforward, this approach fails to take advantage of full-azimuth and long-offset coverage from the OBN data. Combining OBN and streamer data overcomes the limit of OBN fold coverage and helps to build a more accurate velocity model than with streamer data alone. The reverse time migration (RTM) angle gather domain is natural for reconciling streamer and OBN data. Roberts et al. (2011) incorporated narrow-azimuth towed-streamer data and OBN data to build tilted transverse isotropic (TTI) models with RTM angle gathers. A high-resolution supra-salt velocity update normally requires a higher frequency migration (e.g., common vector offset Kirchhoff migration). Kirchhoff migration uses surface offsets from the shot to the receiver, which creates challenges for joint tomography because of the difference between the source and receiver datums of OBN and streamer data. Figure 1 shows the shot and receiver datum for streamer data and an OBN's down-going wave.

We present a joint tomography method that can reconcile surveys with different shot and receiver datums. We tested our method on an OBN survey in deep water Gulf of Mexico, where the water depth is approximately 2 km. Hexagonal binning was used for OBN binning prior to the migration. The OBN full-fold coverage was around 300 km^2, positioned directly above the subsalt reservoir target zone. An overlapping wide-azimuth (WAZ) survey covering ~1200 km^2 was used for joint tomography.

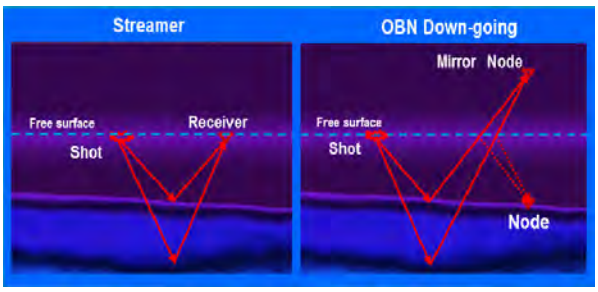

Figure 1 *Ocean bottom node (OBN) down-going wavefield and streamer data have different shot and receiver datums.*

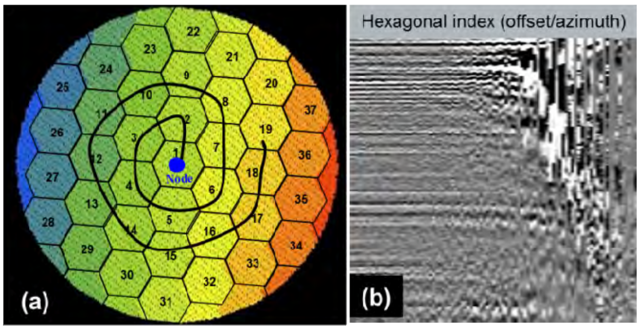

Figure 2 *Hexagonal binning for ocean bottom node (OBN) data: (a) Hexagonal index numbers for a single node. (b) OBN snail gather.*

OBN hexagonal binning

Inspired by dense full-azimuth (FAZ) land data processing in common offset vector bins, OBN down-going wavefield data are binned using a hexagonal offset vector binning technique. The OBN survey consists of ~1000 nodes with 300 m x 300 m node spacing. The shot patch is designed in a circular shape with ~30 km radius and 50 m x 40 m shot spacing. First, the hexagonal binning calculates and assigns a hexagonal index to the data based on the azimuth and offset (Figure 2a). Next, traces with the same hexagonal index number from different nodes are migrated together. Then snail gathers can easily generate data in the sort order of common depth point and hexagonal index. Figure 2b shows a snail gather example. In each radial offset class of a snail gather, traces are sorted according to increasing azimuth. A snail gather display is particularly suitable for checking azimuthal effects because wobbling in these gathers is evidence of kinematic variations with azimuth. If strong wobbling is present, orthorhombic instead of TTI model building should be implemented to flatten gathers in all azimuths.

For tomography, gathers are sorted into azimuthal offset gathers. In each azimuthal class, data are ordered according to increasing offset value. Figure 3 shows the comparison between WAZ Kirchhoff and OBN down-going common azimuth gathers. OBN gathers have a curvature that is consistent with the corresponding WAZ gathers. Benefit from acquisition settings such as stationary receivers and quieter environment, OBN data have less noise compared to streamer data. Hence, OBN Kirchhoff gathers have a higher S/N than WAZ Kirchhoff gathers, which aids in curvature picking. Full-azimuth coverage and higher S/N in the OBN data can provide better curvature information for tomography.

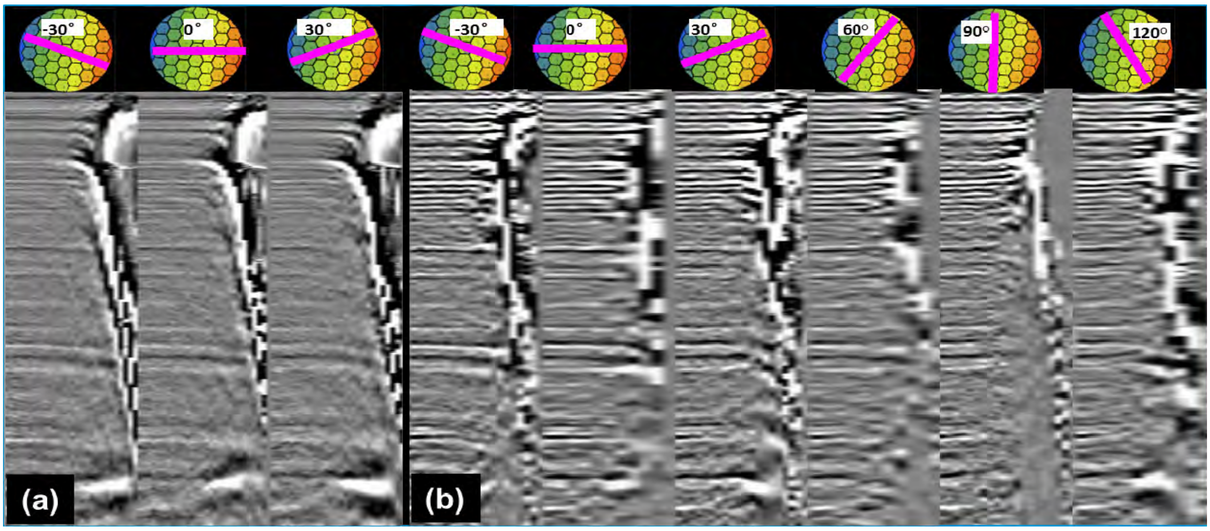

Figure 3 *(a) Pre-migration de-ghosted WAZ Streamer Kirchhoff offset gathers. (b) OBN azimuthal Kirchhoff offset gathers. The magenta bar indicates the source-receiver azimuth of the gather.*

Joint OBN-WAZ tomography for supra-salt regions

Thanks to their high-frequency content, Kirchhoff gathers are an excellent input for high-resolution tomography in supra-salt sediment tomography regions. Prior to model building, full pre-processing flows are applied to both the OBN and WAZ data. OBN data have limited up-going wavefield midpoint coverage for shallow reflectors caused by sparse node spacing. Therefore, we exclusively use mirror migrations of the down-going wavefield for sediment tomography. Common azimuth gathers of the OBN down-going mirror Kirchhoff migration and the WAZ Kirchhoff migration for the OBN+WAZ joint tomography are used. The input model for the joint tomography is derived from two iterations of WAZ-only tomography.

Since OBN and surface-towed WAZ streamer data have different shot and receiver datums, extra care must be taken during joint tomography. The joint tomography procedure is as follows:

- First, we bin and migrate WAZ and OBN data separately. While WAZ data are binned into three azimuths (0º, 30º, and -30º), OBN data are binned using the hexagonal binning technique into six azimuths (-30º, 0º, 30º, 60º, 90º, and 120º). Then, WAZ data are migrated using a conventional model, and OBN data are migrated using the corresponding mirror model (i.e., water layer flipped above sea level).
- Next, we extract curvatures separately from the OBN and WAZ common-azimuth Kirchhoff migration gathers.

- After that, we use a non-linear slope tomography (Guillaume et al. 2008) to kinematically demigrate the picked events into the un-migrated domain, providing the kinematic invariants. These invariants are independent of migration models. For each individual offset or azimuth trace, these invariants include one pair of source/receiver positions, the traveltime, and the traveltime slope computed from ray tracing. As a result, OBN and WAZ shot and receiver geometries assigned to these invariants are taken into account in this step.
- We then input all the resulting invariants from OBN and WAZ simultaneously into the joint inversion process to obtain a velocity that flattens gathers across all azimuths of both the OBN and WAZ data.

Results

Gamma is a second order fitting of the gather curvature. Gamma is 1 if the gather is perfectly flat. If the data are under-corrected, gamma is greater than 1; if the data are overcorrected, gamma is less than 1. Figure 4 shows gamma before and after joint tomography. Before joint tomography, WAZ gathers were reasonably flat because the input model came from two iterations of WAZ-only tomography (Figure 5). We observe that the OBN gamma is smaller along the WAZ shooting direction at -30º, 0º, and 45º azimuths, which is expected, and larger along the other three azimuths. After joint tomography, gamma values of both WAZ and OBN are brought closer to one in all azimuths, and OBN gamma distribution become more centered around 1 based on the OBN gamma histogram (Figures 3a and 3b). Moreover, gamma values are consistent among all azimuths, which indicated that the velocity update from joint tomography is not biased towards a specific direction.

Discussion

Joint tomography benefits from full-azimuth coverage in the OBN data and extended area coverage from WAZ data, which leads to a better velocity model. By taking into account all azimuths simultaneously, this joint tomographic inversion is more stable and robust. It is also easy to determine if any curvature inconsistencies exist across azimuths. If an azimuthal discrepancy does exist after several iterations of joint tomography, orthorhombic tomography can be implemented using the same method. Another advantage of this joint tomography method is that it is not restricted to only Kirchhoff gathers, but it can also handle other migrated gathers such as controlled beam migrated offset gathers and RTM offset gathers. For complicated media such as subsalt areas, RTM offset might result in a better curvature and event sampling compared to angle gathers. In such cases, this joint tomography flow can be easily extended to reconcile OBN and streamer RTM offset gathers for better velocity models.

Conclusions

We presented a joint OBN/streamer tomography method that uses surface-offset gathers from surveys with different shot and receiver datums. By incorporating both OBN and streamer data in tomography, the aperture and coarse sampling limitations of OBN surveys can be overcome, and the full-azimuth coverage, better low frequencies, longer offsets, and higher S/N of OBN data can benefit tomography. This joint tomography flow can be extended to reconcile OBN and streamer RTM offset gathers to obtain better velocity models in subsalt regions.

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References

Beal, E., Salo, E., Corcoran. C., [2014] Lessons from the deep – processing ocean bottom Seismic data. *84th SEG Annual International Meeting*, Expanded Abstracts, 3679-3683.

Beaudoin, G., and Ross, A., [2007] Field design and operation of a novel deepwater, wide-azimuth node seismic survey. *The Leading Edge*, **26**, 494-503.

Boelle, J.-L., Lecerf, D., Lafram, A. and Cantillo, J. [2010] Ocean bottom node processing in deep offshore environment for reservoir monitoring. *80th SEG Annual International Meeting*, Expanded Abstracts, 4190-4194.

Guillaume, P., Lambaré, G., Leblanc, O., Mitouard, P., Le Moigne, J., Montel, J.-P., Prescott, T., Siliqi, R., Vidal, N., Zhang, X. and Zimine, S. [2008] Kinematic invariants: An efficient and flexible approach for velocity model building. *78th SEG Annual International Meeting*, Expanded Abstracts, 3687-3692.

Roberts, M., Dy, T., Ji, S., Reasnor, M. and Shepherd, D. [2011] Improving Atlantis TTI model building: OBN+NATS, prism waves & 3D RTM angle gathers. *81st SEG Annual International Meeting*, Expanded Abstracts, 3238-3242.

Stophin, A., Mc Rae, M., Lepre, L., Reasnor, M. and Gaudin, B. [2008] Constructing an anisotropic velocity model for ocean bottom seismic node data. *78th SEG Annual International Meeting*, Expanded Abstracts, 993-997.

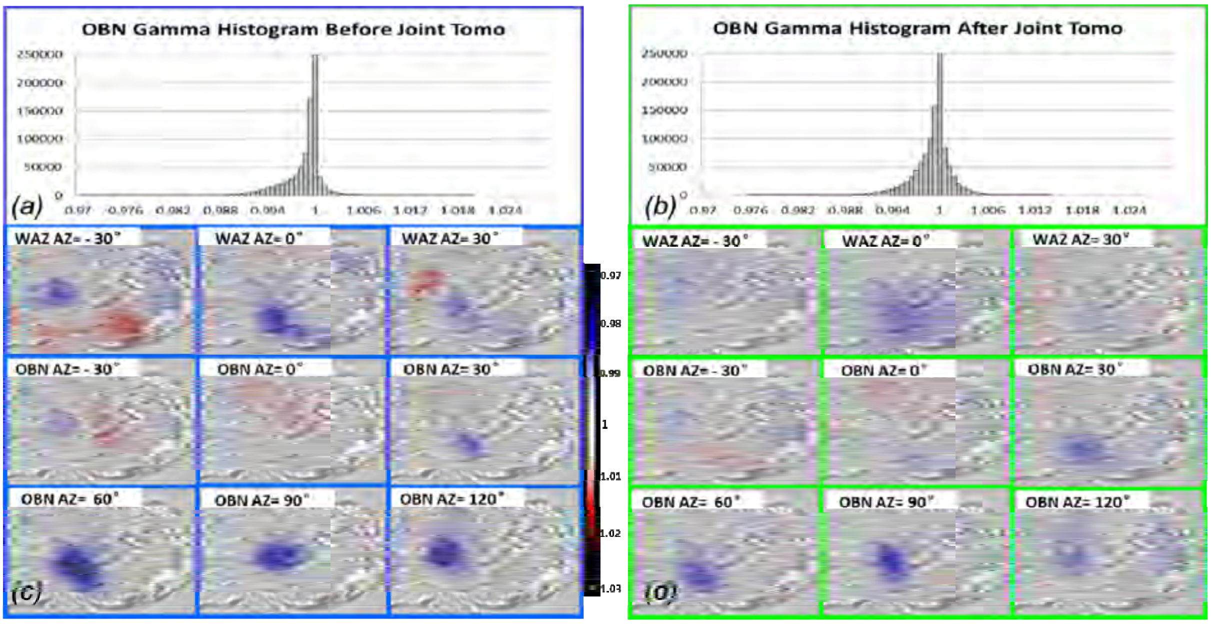

Figure 4 *Gamma comparison: OBN gamma histogram (a) before and (b) after joint tomography. Gamma depth slice (c) before and (d) after joint tomography.*

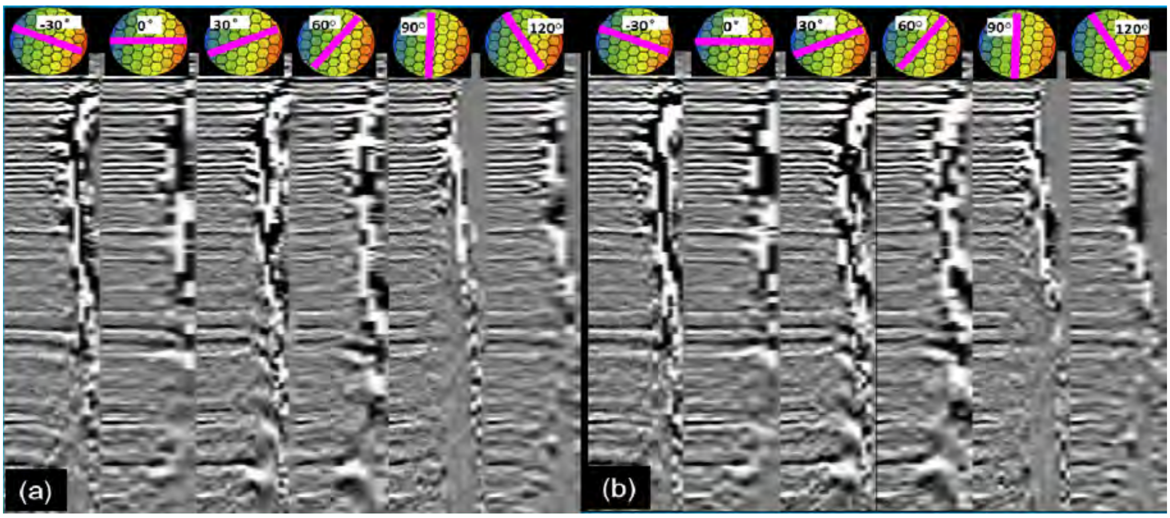

Figure 5 *OBN gathers comparison: (a) Before and (b) after joint tomography.*