Mitigating Uncertainties in Towed Streamer Acquisition and Imaging by Survey Planning

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SUMMARY

Uncertainties in seismic images or reservoir characterisation can very often been associated with lack of resolution, illumination problems, or the inability to invert for accurate velocity models. Uncertainties may also be caused by general data quality issues like noise content as well as acquisition and processing footprints. Provided the geophysical challenges are well understood, such uncertainties can be mitigated already in the planning phase of a seismic acquisition project. Geophysical survey planning typically considers requirements for, e.g., temporal and spatial resolution, illumination at target level and also looks into the suppression of incoherent and coherent noise (e.g., multiple energy). Typically, the geophysical objectives and quality requirements have to be traded against survey cost and may be constrained by operational aspects.

Combining state of the art towed streamer acquisition technology with advanced processing and imaging methods enables us to mitigate some of these uncertainties. This paper discusses issues and solutions related to illumination, footprints, and resolution. Also the benefit from utilising seismic wave types in addition to primary reflections and other geophysical methods is addressed.

Introduction

Uncertainties in seismic images or reservoir characterisation can very often been associated with lack of resolution, illumination problems, or the inability to invert for accurate velocity models. Uncertainties may also be caused by general data quality issues like noise content as well as acquisition and processing footprints. Provided the geophysical challenges are well understood, such uncertainties can be mitigated already in the planning phase of a seismic acquisition project. This paper focusses on state of the art towed streamer applications in marine seismic.

Survey Planning for Towed Streamer Acquisition

Proper geophysical survey planning should precede any 3D towed streamer acquisition. In survey planning, geophysical objectives are set to deliver an optimum image of a geological target and to allow qualitative or quantitative inversion of the seismic data into rock properties. Key issues that are typically considered are requirements for, e.g., temporal and spatial resolution, illumination at target level and offset ranges needed for AVO/AVA analysis. An acquisition design study traditionally also looks into the suppression of incoherent and coherent noise (e.g., multiple energy). Typically, the geophysical objectives and quality requirements have to be traded against survey cost and may be constrained by operational aspects.

Illumination

Cost effective single vessel narrow azimuth acquisition is the most frequently used 3D seismic survey method with towed streamer technology (Figure 1). However, in the presence of large structural dip, illumination holes can occur for large offsets, e.g., for parallel shooting in up-dip direction (e.g., Long *et al*., 2004). Anti-parallel shooting can improve the illumination uniformity. Parallel race track shooting can also lead to processing artefacts at sail line boundaries, especially if abrupt changes in azimuth are not handled properly in processing.

The geological environment on its own can cause severe challenges for structural imaging. E.g., for sub-salt targets, wave propagation may become so complex, that standard narrow azimuth acquisition very often cannot provide continuous and uniform illumination at target level. Uncertainties in sub-salt imaging can then be reduced by an increased acquisition effort, i.e., data with a much richer azimuth and offset distribution is acquired. Multi-azimuth (MAZ), wide-azimuth (WAZ), rich-azimuth (RAZ) and full-azimuth (FAZ) survey geometries (Figure 2) have been utilised in recent years to reduce uncertainties in imaging (Long *et al*., 2014, Mandroux *et al*. 2013, Moldoveanu *et al*. 2008, Howard, 2007, Keggin *et al*., 2002). The effectiveness of such more advanced (and costly) survey geometry is very often studied in the pre-survey planning phase by comprehensive ray tracing or finite difference modelling based on models that represent the geology (e.g., Regone, 2006, Hoffmann *et al*., 2002).

Broadband seismic and 4D

Ghost reflections from the sea surface have been limiting the bandwidth of towed streamer data in the past. The introduction of dual-/multi-component streamer has enabled the industry to overcome the receiver ghost problem (Carlson *et al*., 2008). Sensors with complementary ghost response functions are utilised to remove ghost reflections in an accurate and robust way. The removal of the receiver ghost increases the seismic bandwidth and thus provides better resolution for interpretation. The ability to remove the ghost accurately allows a deeper tow of the streamer. Deeper tow improves the signal-to-noise ratio especially at the low frequency end of the seismic bandwidth. Improved low frequency content enhances the quality and accuracy of seismic inversion and reservoir characterisation.

However, broadband seismic requires increased fidelity and accuracy in acquisition and processing technology similar to 4D monitoring. Increased positioning accuracy, streamer steering as well as source steering have become requirements for modern seismic acquisition. Marine sources must generate a signal output that is stable in amplitude and phase over many thousand shot points to remove uncertainties in the acquisition phase.

Towards complete wavefield acquisition and imaging

The uncertainty in a seismic image is usually linked to the uncertainty of the seismic velocity model. Velocity errors in the shallow overburden can easily translate into miss-positioned reflectors at target level. It has been demonstrated that full waveform inversion (FWI) can resolve velocity anomalies in the overburden that are associated with, e.g., channels, pock-marks or gas-pockets (Rønholt *et al*., 2014). FWI techniques make commonly use of post-critical, refracted seismic events which are recorded at longer offsets.

3D towed streamer acquisition in shallow water can as mentioned earlier in this abstract lead to illumination holes at swath boundaries due to lack of near offset data. The lack of data not only creates a footprint in the image, but also limits the ability to quality control migration velocities based on flatness of the gathers, and also hinders AVO/AVA type studies. It has been demonstrated recently that the concept of virtual source imaging (Wapenaar et. al, 2010) can be extended to multi-senor streamer acquisitions to utilize sea surface reflected (downgoing) wavefield energy that provides the near-surface information missing from primary reflections.

Survey planning for towed marine streamer seismic has traditionally focused on capturing and proper sampling of primary reflections from the subsurface. Recent case studies have demonstrated the benefits of other wave types, like multiples and refractions, in removing uncertainties in imaging. Survey planning efforts should therefore have focus on optimising the recording of the complete wavefield beyond primary reflections going forward.

Combining Seismic and EM acquisition

Survey planning for seismic should ideally also consider the integration of alternative geophysical methods. As such the characterisation of reservoirs or shallow anomalies in the overburden can be complemented by controlled source electromagnetic data (CSEM). CSEM data enables the sub surface resistivity to be determined early in the exploration cycle (e.g., Constable, 2010). Resistivity is known to be sensitive to the presence of hydrocarbons. With modern towed streamer EM systems it is now possible to acquire CSEM data simultaneously with dual-sensor streamer seismic using a single vessel (Engelmark *et al*., 2014).

Conclusions

Survey planning is vital to establishing optimal seismic acquisition and processing solutions in order to meet geophysical and geological objectives. The associated survey modelling should seek to establish the optimum sub-surface illumination for a range of source and receiver geometries using the complete set of recorded waves and incorporating additional geophysical measurements such as towed streamer EM.

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Figure 1 *Cost effective single vessel narrow azimuth acquisition is the most frequently used 3D seismic survey method with towed streamer technology.*

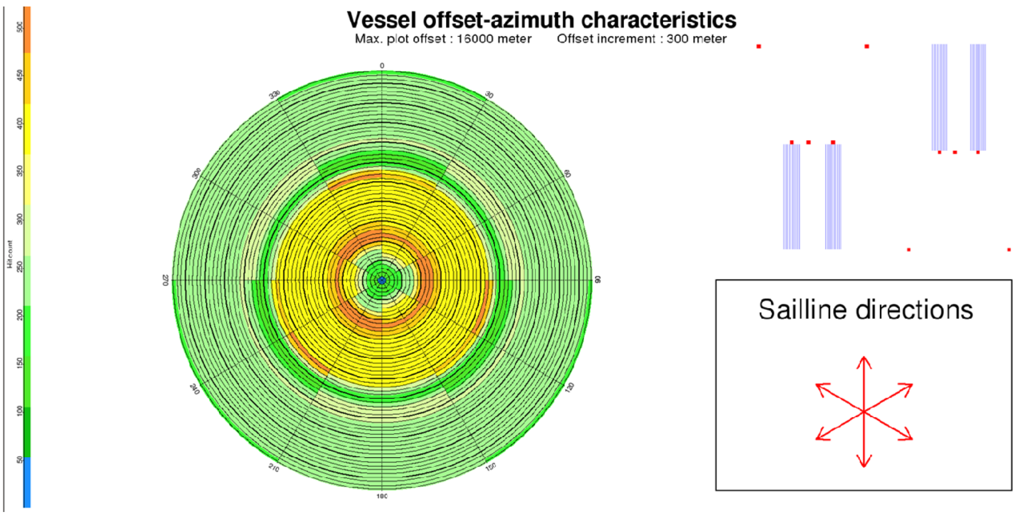

Figure 2 *State of the art FAZ solutions can be achieved by combining a five vessel WAZ template (upper right corner) with the MAZ technique (in this case 3 main shooting directions). This novel FAZ design delivers continuous azimuth coverage and offsets up to ca 16km.*

References

D.H. Carlson, W. Söllner, H. Tabti, A. J. Day and M. Widmaier, [2008] Increased Resolution of Seismic Data from a Dual-sensor Streamer Cable. *70th EAGE Conference and Exhibition*, 2008.

Constable, S. [2010] Ten years of marine CSEM for hydrocarbon exploration. *Geophysics*, **75**(5), 75A67-75A81.

Hoffmann, J., Long, A., Kajl, B., Strand, C., [2002] The value of subsurface coverage modelling for seismic acquisition analysis. *SEG Technical Program Expanded Abstracts 2002*, 37-40.

Howard, M., [2007] Marine seismic surveys with enhanced azimuth coverage: Lessons in survey design and acquisition. *The Leading Edge*, **26**(4), 480-493.

Engelmark, F., Mattsson, J., McKay, A., and, Du, Z. [2014] Towed streamer EM comes of age. *First Break*, **32**(4).

Keggin, J., Widmaier, M., Hegna, S., and Kjos, E., [2002] Attenuation of Multiple Diffractions by Multi-Azimuth Streamer Acquisition. *EAGE 64th Conference Abstracts*.

Long, A., Campbell, S., Fishburn, S., Brandsberg-Dahl, S., Chemingui, N., and Dirks, V., [2014] No-compromise marine seismic: A full-azimuth survey design for total-wavefield velocity model building and imaging in the deep-water Gulf of Mexico. *SEG Technical Program Expanded Abstracts 2014*, 52-56.

Long, A., Ramsden, C., Hoffmann, J., [2004] On the issue of strike or dip streamer shooting for 3D multi-streamer acquisition. *Exploration Geophysics*, **35**(2), 105-110.

Mandroux, F., Ting, C., Montgomery, B., and A. Lenart, [2013] Staggered marine acquisition design for complex imaging. *SEG, Expanded Abstracts*, 26-30.

Moldoveanu, N., Kapoor, J., and M. Egan, [2008] Full-azimuth imaging using circular geometry acquisition. *The Leading Edge*, **27**(7), 908-913.

Regone, C. [2006] Using 3D finite-difference modeling to design wide azimuth surveys for improved subsalt imaging. *SEG, Expanded Abstracts*, 2896-2900.

Rønholt, G., Lie, J.E., Korsmo, O., Danielsen, B., Brandsberg-Dahl, S., Brown, S., Chemingui, N., Valenciano Mavilio, A. and Whitmore, D. [2014] Broadband velocity model building and imaging using reflections, refractions and multiples from dual-sensor streamer data. *76th EAGE Conference & Exhibition.*

Wapenaar, K, Slob, E., Snieder, R., and Curtis, A. [2010] Tutorial on seismic interferometry: Part2 – Underlaying theory and new advances. *Geophysics*, **75**(5), 75A211-75A227.