Marine full-azimuth field trial at Heidrun revisited
Marianne Houbiers¹*, Thomas Røste¹, Mark Thompson¹, Bartosz Szydlik², Teufelin Traylen², and David Hill²
1) Statoil Research Center
2) WesternGeco

SUMMARY
In 2008, a marine field trial with a coil shooting design was acquired at Heidrun. In the preliminary processing of the data, some noise filters were used that assume straight line geometries and thus do not take the 3D nature of the data properly into account. Moreover, due to sparseness of data outside the 7 km² target area, a limited migration aperture was used. As a result, the lateral resolution of the data is less good than in the conventional streamer data, causing loss of some details of the geological structure.

To overcome the challenges with the lateral resolution, the research project was recently continued with a reprocessing of the coil survey data. In reprocessing, less aggressive noise filters were used, and data from a conventional narrow azimuth survey were tied in to fill holes at the edges of the survey area. This yields a better multiple model and allows for a larger migration aperture. The resulting images are less smeared, fault planes are clearer, and fault blocks well defined. In particular, the coil survey may give additional information to define fault planes and rotated fault blocks in the shallow part of the reservoir.

INTRODUCTION
The Heidrun field is located in the Norwegian Sea, 100 km from the coast of Mid-Norway. The strata below the Base Cretaceous Unconformity (BCU) are heavily faulted, causing imaging challenges. In particular, previously acquired conventional streamer data show that faults below the BCU in some areas of the reservoir are unclear and dips are conflicting. A modeling study showed that these imaging problems could be resolved with a full-azimuth (FAZ) survey design (Houbiers and Thompson, 2010).

To validate the conclusions from the modeling study, a small field trial with coil shooting design (French, 1984; Durani et al, 1987; Moldoveanu, 2007; Ross, 2008), was acquired at Heidrun in 2008, using a conventional seismic vessel with a single source, towing 10 streamers with a length of 4500m, streamer separation of 75m, and group distance of 12.5m (3.125m single sensors). The target area of the coil shooting field trial is a square area of 2.625x2.625 km². The survey design consisted of a ‘dahlia’ pattern with intersecting coils covering the target area, see Figure 1. The coils are slightly irregular to avoid safety zones around obstacles in the field, and an additional straight infill line was acquired to compensate for missing azimuths. The coils had an approximate radius of 5625m, and the source separation was 25m. The fold of the survey, color coded in 25x25m² bins, is displayed in Figure 1. The small square in the middle denotes the target area. Note that the target area has full azimuth coverage with high fold, except for the lower right corner of the target zone. Outside the target zone, the fold of coverage decreases rapidly, having implications for the size of the migration aperture.

Figure 1. Total fold of coil shooting field trial in 25x25m bins. The small square denotes the target area. The arrow points to North.

The main steps in data processing are removing as much noise as possible by applying filters in several passes, multiple removal, regularization, and imaging. Obviously, the biggest challenge in processing the coil survey data is that the data are not sampled on a regular grid, and that the fold varies substantially from one bin to the next, even within the target zone, see Figure 1. Preliminary processing was done immediately after acquisition (Houbiers et al. 2009). The processing sequence should in principle incorporate the full 3D nature of the data. However, as a first attempt, a quasi 2D assumption was adopted, where shot gathers are assumed to be on straight lines, instead of on curved paths, and migration is done in three azimuth sectors. These simplifications obviously have an impact on the quality of the resulting images.

The preliminary results indicated that there is little remnant noise and multiple energy left in the coil survey data, giving rise to clear images (Houbiers and Thompson, 2010). The images show fewer conflicts with respect to fault definitions and dip directions in the reservoir section, compared to the conventional streamer data. Also, the flanks of the structure with rotated fault blocks are imaged well. However, the preliminary images from the coil shooting field
trial are smeared and have a lower lateral resolution, which may be the reason why some details of the structure are lost. For instance, some fault structures can be misinterpreted as flexures, or are not imaged at all.

The loss of lateral resolution in the preliminary processing is assumed to be caused by the use of noise removal routines which assume straight line geometries (in particular due to FK-filtering and a 2D radon transform), and the limited migration aperture used in the migration (due to sparseness of the data outside the target zone). To improve the lateral resolution, the data was reprocessed using less aggressive noise filters aiming at preserving as much information as possible. In addition, data from a conventional survey are tied in at the edges of the survey area, allowing for a larger migration aperture. The main differences with the preliminary processing and the results of the reprocessing are described in this paper.

**REPROCESSING STEPS**

**Denoise**

The main goal during reprocessing is to improve the lateral resolution of the seismic images by limiting the damage done by noise filters. During reprocessing of the coil survey data, a noise filter is applied to the single sensor raw data, instead of the onboard noise filter applied in the preliminary processing. The noise filter used in the reprocessing has a longer window and removes more swell noise and long-offset noise, see Figure 2. In addition, a 2:1 trace drop to 6.25m trace spacing (instead of 4:1 to 12.5m onboard) is applied because this better preserves the amplitudes of the diffraction tails. The improved noise filter allows a milder anomalous amplitude attenuation filter and no FK-filter is applied in the reprocessing, in contrast to the preliminary processing in 2008.

![Figure 2. Comparison of noise filter applied to shot gather onboard and in reprocessing.](image)

**Demultiple**

Subsequently, free surface multiples are suppressed with generalized surface multiple prediction (GSMP) (Dragoset et al., 2008), followed by least squares adaptive subtraction (LSAS). The sparseness of data outside the target zone gives rise to a suboptimal multiple model prediction, because it decreases the probability for finding representative traces to create the multiple contribution gather (MCG) around each source-receiver (SR) trace. To increase the number of traces to choose from, data from a conventional survey acquired in 2006 are tied in before GSMP. This particular survey is chosen over a conventional survey acquired in 2008 because of better similarity in the water temperature and tidal statics. Tidal statics correct the primaries, but not the multiples. In fact, inconsistencies are growing for each order of multiples. The tidal statics for the coil data are of the order of 2ms. For 3rd and 4th order multiples this can generate time differences of 6-8ms, which can affect the MCG stacking process, in particular because the traces contributing to each MCG may originate from several coils as well as the conventional survey. Such inconsistencies cause jittering in the MCG (in particular on the far offsets) and can deteriorate the GSMP process.

The jittering is a problem embedded in coil data and in general in wide azimuth data, but can be reduced with an optimal MCG neighbor search scheme based on suitable geometric attributes as midpoint, offset, and azimuth. One would furthermore expect the jittering to minimize by prioritizing the same coil when choosing the traces for creating the MCG of a given trace SR, and only if that is not possible, choosing from another coil or else from the conventional survey. Yet the best GSMP-results are obtained when no ranking is applied in the neighbor search. In the preliminary processing, equal weights were assigned to offset and azimuth. However, in the current reprocessing, the azimuth weight is only 1/5 of the offset weight, and tapered to 0 at an offset of 5000m. In addition, a velocity tapering towards 1500m/s at 5000m offset is used, instead of the NMO velocities. This yields superior results for the MCG, with less jittering and stair casing, and better continuity of the multiple events, see Figure 3. GSMP is stabilized further by applying LSAS in a combined shot-offset domain (in contrast to the offset domain used in the preliminary processing). Despite the larger risk for inconsistencies, tying in the 2006 conventional data in GSMP improves the suppression of free surface multiples from the coil survey, in particular in the overburden, see Figure 4.

**Migration**

In addition to noise filtering, the lateral frequency content of the data is affected by the migration aperture. To allow for a larger migration aperture than used in the preliminary processing, demultiplied data from the 2008 conventional survey are tied in before regularization and migration. For migration, one is only interested in the primaries, and the 2008 conventional survey is chosen over the 2006 survey to minimize 4D effects. However, there are large differences between the coil data and the conventional data, since noise and multiple removal of the 2008 conventional data was
done with a completely different sequence. Ideally both data sets should be put through the same processing sequence to avoid ‘blocky’ data and discontinuities when they are combined into gathers. Since this is not done, an additional 2D radon demultiple is run on the coil data prior to regularization in order to reduce the difference in residual multiple noise between the 2008 aperture data and the coil data. This is not optimal since the 2D radon tends to smear data, and one risks the same loss of lateral resolution as in the preliminary processing. But at least this will give an idea whether the processing changes applied so far have helped.

As in the preliminary processing, the data are regularized in 60° azimuth (reciprocal) and 100 m offset bins. Data are migrated with Kirchhoff pre-stack time migration in each azimuth bin, using an isotropic velocity model based on conventional narrow azimuth data and used earlier in 4D processing. If there would be strong indications of anisotropy, one should estimate an anisotropic velocity model, or a separate velocity model for each azimuth bin, but this is not done here. The aperture used in the migration is 3000m instead of 1700m in the preliminary processing. The final image cube is obtained by stacking the three migrated azimuth bins and matching the temporal frequency content of the coil shooting data to the conventional data.

RESULTS

Figure 5 shows seismic sections from the conventional narrow azimuth, the reprocessed coil survey, and the preliminary processed coil survey along an inline in the upper part of the target zone. The green arrows at depth 2300ms denote the position of the time slices from corresponding structure cubes displayed in Figure 6. The red arrows in the latter figure show the position of the inline in Figure 5.

Figures 5 and 6 indicate an improved lateral resolution of the reprocessed coil survey compared to the preliminary processed data: Fault planes are sharper, and smearing of horizons over the fault planes (e.g. the coal marker around fault F3) is reduced considerably. Furthermore, the noise level in the conventional survey and the reprocessed coil survey is comparable. But compared to the conventional survey, the reprocessed coil survey shows better definition of some faults planes such as the one denoted by F1 (drawn discontinuously to stress the sharpness) and some small faults in the shallower part of the reservoir section which do not go down to the clearly defined coal markers. Note that these small faults have the same dip as the main faults, increasing the confidence in that these faults are real, and not just noise. As a result, one obtains sharper images of the rotated fault blocks at the flanks of the structure.

The time slices from the structure cubes confirm these findings. They cut partially through the reservoir section, highlighting faults and changes in structure. Both the conventional survey and the reprocessed coil survey reveal the two main fault directions present at Heidrun. For this reason, the ‘horizontal’ fault denoted by A in the conventional survey seems to be an artifact. Also, the conventional survey shows a clear acquisition footprint. The fault system is less clear in the preliminary processed coil survey because of inferior lateral resolution, in addition to lack of data in the lower right corner.

Figure 7 shows a small part of the seismic section in Figure 5 for the 0°, 60°, and 120° azimuth bins. The three stacks each give a slightly different picture of the flank of the structure. This may give additional information that can be used for obtaining a better understanding of the reservoir section. Similarly, the position of fault F2 in the reprocessed coil survey in Figure 5 seems slightly different from the position in the conventional survey, and may give rise to uncertainty. But knowing different scenarios and being aware of uncertainty in the interpretation of the subsurface is advantageous when drilling wells.

---

1 The centre axis of the azimuth bins are defined at angles 0°, 60°, and 120° relative to the inline direction of the conventional 3D narrow azimuth survey.
FAZ field trial at Heidrun revisited

Figure 5. Inline section for the conventional (left), reprocessed coil survey (middle), and preliminary processed coil survey (right). The dashed lines indicate preliminary fault interpretations, and the yellow line indicates a coal marker. The letters denote smearing of a fault plane (S), a rotated fault block (R), and specific fault planes (F1-F3). The green arrows show the location of the time slice in Figure 6.

Figure 6. Time slices of structure cube of conventional survey (left), the reprocessed coil survey (middle) and the preliminary coil survey (right) at 2300 ms. The red arrows show the location of the inline section in Figure 5. The letters denote a real fault plane (F1) and an unreal one (A).

Figure 7. Part of inline section in Figure 5, for 0°, 60°, and 120° azimuth stack of the reprocessed coil survey data.

CONCLUSION
Data from a coil shooting field trial acquired at Heidrun were reprocessed with less aggressive noise filters than used in the preliminary processing. This resulted in better preservation of the lateral resolution in the data, and images with less smearing and a better fault definition. The coil shooting images can thus contribute to an increased confidence in and understanding of the subsurface. The field trial shows that the coil shooting design has the potential for focused seismic imaging of the subsurface, but one has to take the 3D nature of the data into account in processing to fully get out this potential.

ACKNOWLEDGEMENTS
The authors would like to thank Statoil ASA for permission to publish this work, and the Heidrun Unit partners Petoro AS, ConocoPhillips Skandinavia AS, and Eni Norge AS for allowing use of the conventional steamer data.
EDITED REFERENCES
Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2011 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES
Dragoset, B., I. Moore, M. Yu, and W. Zhao, 2008, 3D general surface multiple prediction: An algorithm for all surveys. Presented at the 78th Annual International Meeting, SEG.