IsoMetrix; Isometrically sampled towed-streamer marine seismic data

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Abstract

IsoMetrix is a new type of marine towed-streamer seismic measurement that mitigates for the limited crossline sampling of the towed marine seismic method. Using this new multi-measurement system it is possible to accurately reconstruct the upgoing wavefield between streamers. The integrated acquisition and processing system delivers deghosted reconstructed data, in near realtime, on the vessel as a standard deliverable.

Recent testing and production surveys demonstrate the value of the multimeasurements to measure the 3D wavefield at much higher resolution than with existing technology. As the industry gains experience with this technology any limitations of the reconstruction will become clearer but early results are already showing significant value.

Introduction

The quality of the marine towed-streamer measurement has improved immensely over the last decades. With the introduction of the 3D method in the 80s, much more of the energy scattered from complex geobodies could be captured. Further improvements such as point-receiver, dual tow depth, dual component and streamer steering have each incrementally improved the seismic measurement. However, one major limitation of the towed-streamer seismic method still remains; to acquire data efficiently and with low operational risk the streamer separation (crossline receiver sampling) must be wider than is desirable and considerably wider than the inline sampling (trace interval). The traditional marine towed-streamer method measures the pressure wavefield un-equally (or non-isometrically), resulting in crossline aliasing.

We introduce a new type of marine seismic measurement which compensates for the limited crossline sampling of the towed marine seismic measurement and additionally accommodates 3D receiver deghosting. This paper will provide general information on the theory behind IsoMetrix and provide some results from field tests through to full commercial deployments.

Multisensor streamers and Generalized Matching Pursuit

At its core IsoMetrix is a towed-streamer platform that measures the pressure wavefield, and the vertical and crossline components of the water column particle acceleration wavefield i.e. a multisensor measurement system. The value of the multi-measurement was introduced by Robertsson et al 2008.

To summarize the equation of motion relates particle velocity to the spatial gradient of the pressure wavefield as:

$$\nabla P = -\rho \partial V / \partial t$$

Figure 1. Equation of motion.

Intuitively we expect that having access to the gradient of the pressure wavefield will be beneficial to understand the shape of the recorded wavefield away from the recording location. A number of people have been credited with developing the multi-channel sampling theorem, including Linden (1959), which shows how to reconstruct the wavefield between the recording locations (using the amplitude and the gradient) as long as the spatial bandwidth of the measurement is limited. For single-channel reconstruction, the bandwidth is limited to half the sampling frequency, but for multichannel reconstruction in which the spatial gradient of the wave-field is also measured, the bandwidth is only limited to the sampling frequency.

$$(\gamma o) = \sum_{m=-\infty}^{\infty} \left\{ p\,\frac{2m}{\sigma} \right\} + \left(y_0 - \frac{2m}{\sigma} \right)$$

$$\times\, \partial_y p \, \left(\frac{2m}{\sigma} \right) \Big\} \, sinc^2 \left(\sigma \frac{y_0}{2} - m \right)$$

Figure 2. Linden multi cannel.

With some additional work it was possible to develop the pressure gradient from the multisensor measurement and make use of this multi-channel reconstruction methodology.

Figure 3 illustrates this in cartoon form. The two graphs illustrate single and multi channel reconstruction of a waveform propagating across the spread (blue curve). The horizontal location of the blue dots represents the crossline streamer (measurement) location. With single channel sampling (top graph), multiple waveforms can be reconstructed which honor the spatial measurement. However, with multichannel reconstruction (bottom graph) in which both amplitude and gradient are measured the original waveform can be accurately reconstructed.

However, the goal for IsoMetrix is not to reconstruct the full wave-field at twice the spatial sample rate but rather to reconstruct the upgoing (deghosted) wavefield at much higher reconstruction rates i.e. past the limitations predicted by multi-channel signal theory.

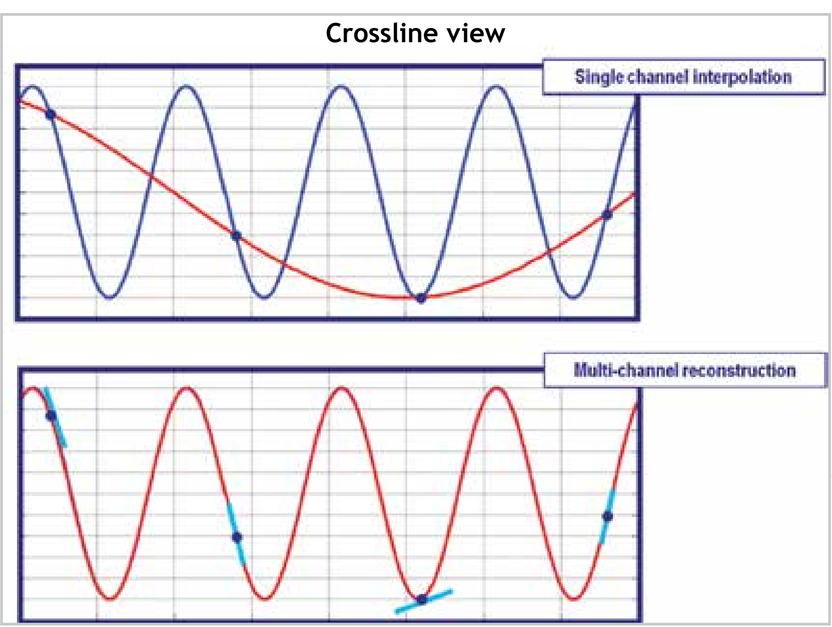

Figure 3. Single channel vs multichannel reconstruction. With single cannel reconstruction (top) only the wavefield amplitude at the streamer locations is measured. A high frequency waveform (blue) will be aliased with such sparse sampling. With multi-channel reconstruction (bottom), both the wavefield amplitude and gradient are measured and the high frequency wave form can be accurately reconstructed.

The methodology to achieve this has been addressed in a number of papers (Özdemir et al 2010, Vassallo et al 2011, Özbek et al 2011, Özbek et al 2010, Özdemir et al 2011) and is termed Generalized Matching Pursuit (GMP). In simplistic terms GMP relies on a number of aspects of the measurement to achieve Joint Interpolation and De-ghosting (JID):

1. The fact that the measured "downgoing" wavefield contains information about the upgoing wavefield at a different location than the recorded location.

2. The three input datasets (pressure, crossline particle acceleration and vertical particle acceleration)are further constrained by relationships, such as the ghost model, which obey the wave equation.

3. The ghost model enables the use of the vertical pressure gradient (also measured with the IsoMetrix multi-measurement system) for crossline reconstruction; according to signal theory this accommodates reconstruction up to the second order of aliasing.

4. The reconstruction technique uses matching pursuit methodology (Özdemir et al 2010) which is not limited by the traditional sampling theorem and has proven to have much stronger de-aliasing potential than originally predicted.

It is also worth mentioning that the multisensor measurement allows for 3D de-ghosting because the direction of the downgoing wavefield can be derived.

The IsoMetrix Platform

IsoMetrix is a integrated acquisition and processing system. The streamer is populated with densely sampled single sensor hydrophones and single sensor dual component accelerometers. As detailed in **Figure 4**, these single sensor measurements are transmitted onboard and then pass through an intensive noise attenuation workflow before being recorded to tape at a 3.125m trace interval. Following this the dataset is passed through GMP to produce the second deliverable with the receivers sampled on the 6.25m x 6.25m IsoGrid. The IsoGrid is a earth referenced receiver grid with 6.25m x 6.25m spatial sampling.

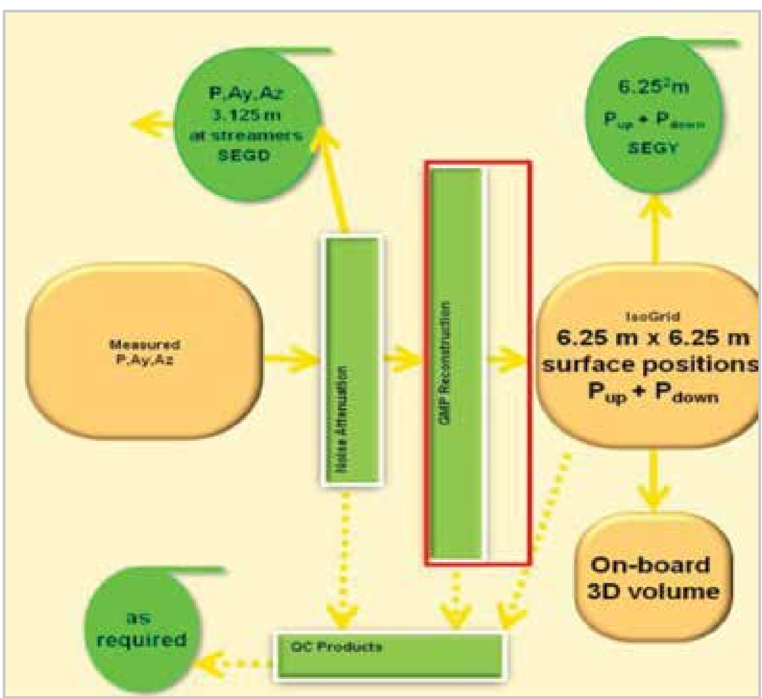

Figure 4. Realtime workflow detailing the two acquisition deliverables.

One of the key challenges in the development of the IsoMetrix technology was addressing the very high levels of low-frequency noise on the acceleration measurement. This issue was previously addressed (Özdemir et al 2012, Teigen et al, 2012). In summary, it is very challenging to make good quality acceleration measurements on a very exposed marine towed-streamer platforms that experience angular, longitudinal and transverse displacement due to the tugging and sea-surface action. In general the amplitude of this noise is inversely proportional to frequency.

Through an integrated engineering effort that resulted in purpose-built sensors, ultrahigh- density sampling and new point-receiver noise attenuation solutions the accelerometer measurement is usable down to very low frequencies (Caprioli et al, 2012).

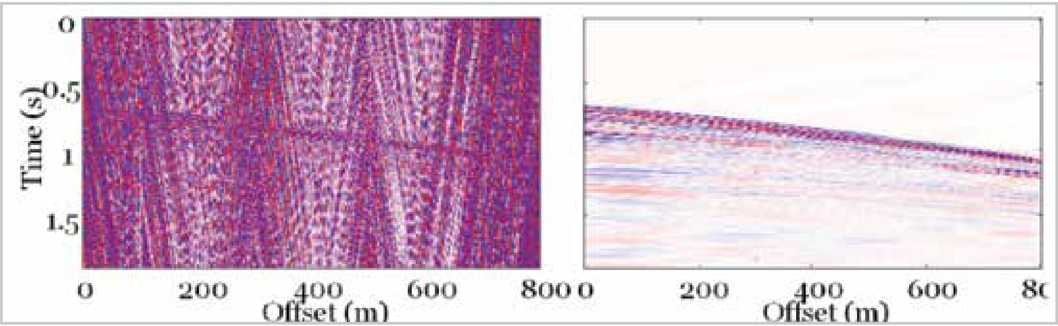

Figure 5. Point-receiver vertical acceleration measurements pre (left) and post (right) noise attenuation.

Results

IsoMetrix has been deployed on a number of projects; both test projects and fully commercial efforts. Initially, the technology was deployed in the North Sea using a very limited acquisition spread of six streamers of 500m length with 75m separation. The results of this project have been extensively described (Vassallo et al, 2012). To summarize, the primary goal of this test was to evaluate the reconstruction, but there were some additional shallow imaging objectives. The data was reconstructed to a surface receiver grid of 6.25m x 6.25m using Generalized Matching Pursuit (GMP). As detailed in figure 6 and 7, the pressure data which is very sparsely sampled in the crossline direction (75m streamer separation) can be reconstructed to 6.25m while preserving steeply dipping out-of-plane energy which would be heavily aliased in the crossline gathers.

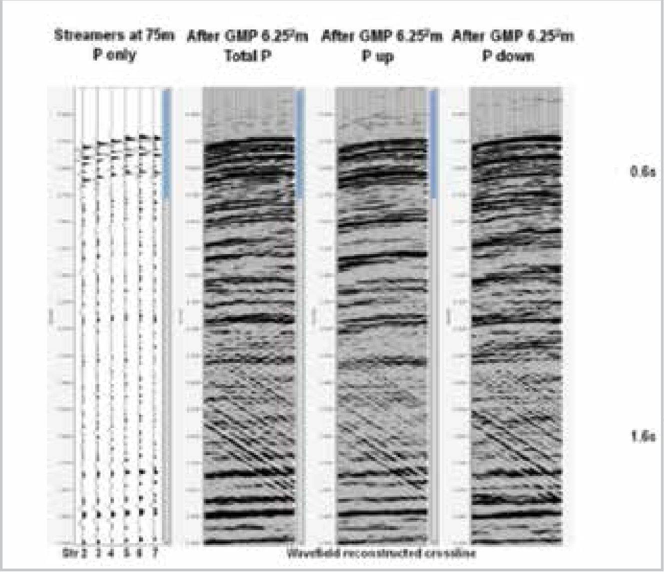

Figure 6. Crossline gather at a common inline offset from a single shot. From left to right – Original pressure only measurement, GMP full wavefield, GMP upgoing wavefield and GMP downgoing wavefield. Note the original measurement is very sparsely sampled, (75m streamer separation) in the pressure only measurement. The reconstruction benefitting from the multi-measurement input has much higher resolution and recovers some linear out-of plane energy which is not identifiable on the pressure only measurement.

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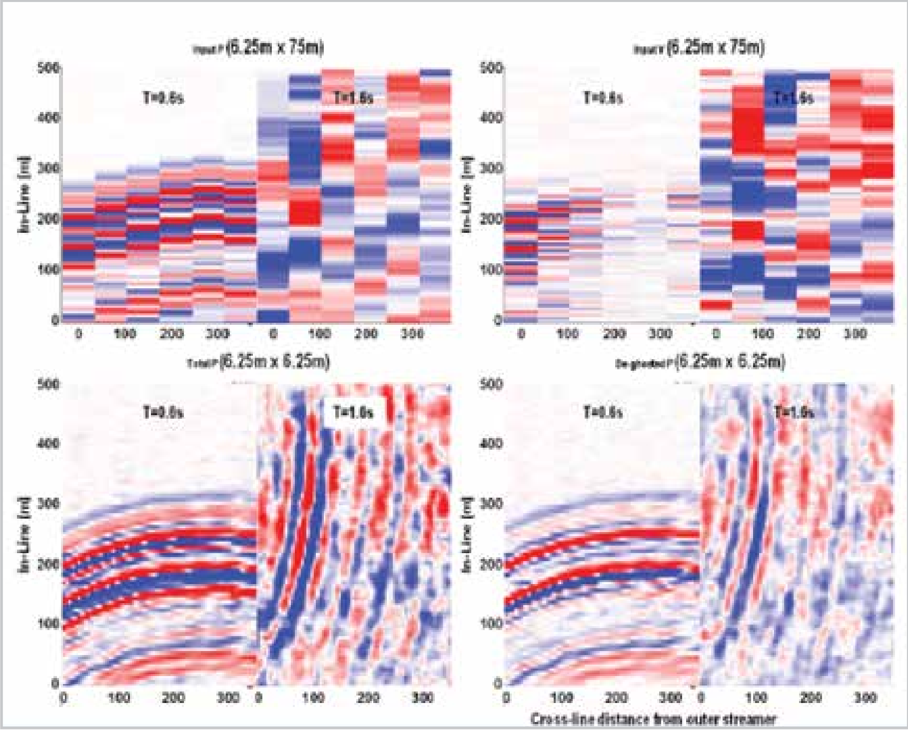

Figure 7. Time slice of the wavefield recorded from the acquisition spread with dimensions of 500m (Streamer length) x 375m (6 streamers at 75m separation). Top left is the pressure recording, top right is the recorded crossline particle velocity. Note while both measurements are well sampled inline, they are very sparsely sampled crossline. The bottom graphs detail the timeslices post GMP; full wavefield (left) and upgoing wavefield (right). The multi-component reconstruction recovers energy which is clearly aliased in the two individual measurements. Also note the higher resolution in the deghosted output.

IsoMetix has since been used on commercial projects with configurations ranging from 6x3000m to 8x6000m.

Conclusions

Initial tests suggest that the goals behind this significant engineering undertaking have been met. The multi-measurement accommodates reconstruction between the streamers of the deghosted wavefield at very high reconstruction rates. As different spread configurations are deployed the industry will gain an understanding of the limitations of this reconstruction methodology.

Even with the understanding we have developed to date the value is very clear. With standard spread configurations it is possible to reconstruct the deghosted wavefield to a 6.25m x 6.25m receiver grid. As well as being very valuable for reservoir targets there are many other benefits. For example, as a by-product of a hydrocarbon exploration survey it will be possible to produce an ultra-high resolution limited depth dataset for shallow drilling hazard evaluation. Additionally, the potential to accurately reconstruct to an earth referenced receiver grid will improve surface repeatability for 4D time-lapse analysis (Eggenberger et al, 2012).

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Semblanza

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Obtuvo su licenciatura en Ingeniería Minera de la Universidad de Staffordshire en Inglaterra. Como geofísico ha desempeñado diversos puestos en Europa, África, Medio Oriente, Rusia, Asia y América Latina. Fue gerente de geofísica para WesternGeco Asia y Australia, con sede en Kuala Lumpur, Malasia, donde manejó la validez científica y técnica de las soluciones sísmicas regionales. Actualmente trabaja en Brasil para WesternGeco Servicos de Sísmica Ltda.