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Demultiple for wide-tow broadband acquisition in a shallow water environment: a case study from the NW shelf, Australia

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SUMMARY

Given its importance, shallow water demultiple has been under constant investigation for many years. Significant progress has been made, effective processing flows have been established, and excellent results have been achieved in different basins across the world. There remain however significant challenges with demultiple in shallow water environments, especially when it comes to broadband acquisition with a wide tow configuration. In this paper, we discuss a shallow water demultiple processing flow used on a recently acquired wide tow broadband dataset in the Northern Carnarvon basin, North West shelf Australia. We demonstrate that the removal of shallow water multiples can be optimized in data acquired in this manner by using a combination of demultiple techniques.

Key words: NW shelf Australia, shallow water demultiple, adaptive subtraction.

INTRODUCTION

The survey is located in the Northern Carnarvon Basin, in an area adjacent to significant discoveries along the Rankin Trend, including Goodwyn, Angel and North Rankin. The Dampier sub-basin hosts over 10km of sediments, dominated by Triassic to Lower Cretaceous successions. Plays exist at multiple stratigraphic levels including oil-prone Jurassic sediments and gas-prone Triassic sediments. Figure 1 shows a map of the survey.

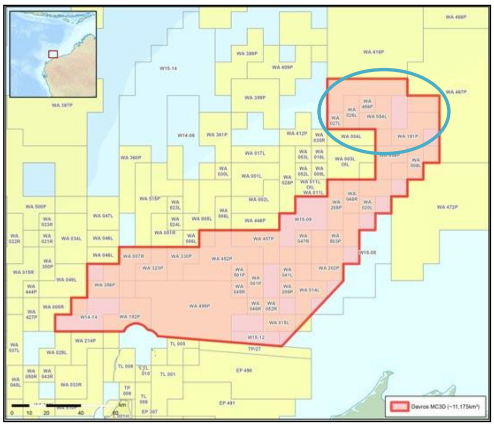

Figure 1: Survey map.

The survey is acquired with variable depth streamers, with a synchronized multi-level broadband source. Receiver depths range from 7m to 50m for the area under discussion - a subset of a multi-phase survey (blue oval in Figure 1). Figure 2 shows plan and section views of the cable configuration.

METHOD AND RESULTS

Data preparation

Data input to demultiple processing have had standard de-noising applied, including swell and linear noise attenuation. The data were acquired with a variable streamer depth, and receiver de-ghosting has been applied. This step was performed using a state of the art 3-D de-ghosting technique that deghosts out-of-plane energy (Wang et al, 2014, Poole, 2013). Figure 3 shows the de-ghosting result on a shot gather.

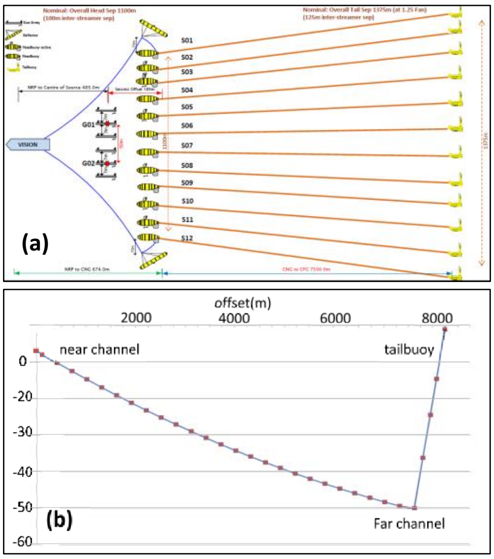

Figure 2: (a): Cable configuration (plan view). Twelve cables: 100m spacing at near channel, 125m spacing at far channel. (b): Cable configuration (profile view of receivers). Near channel depth 7m, far channel depth 50m.

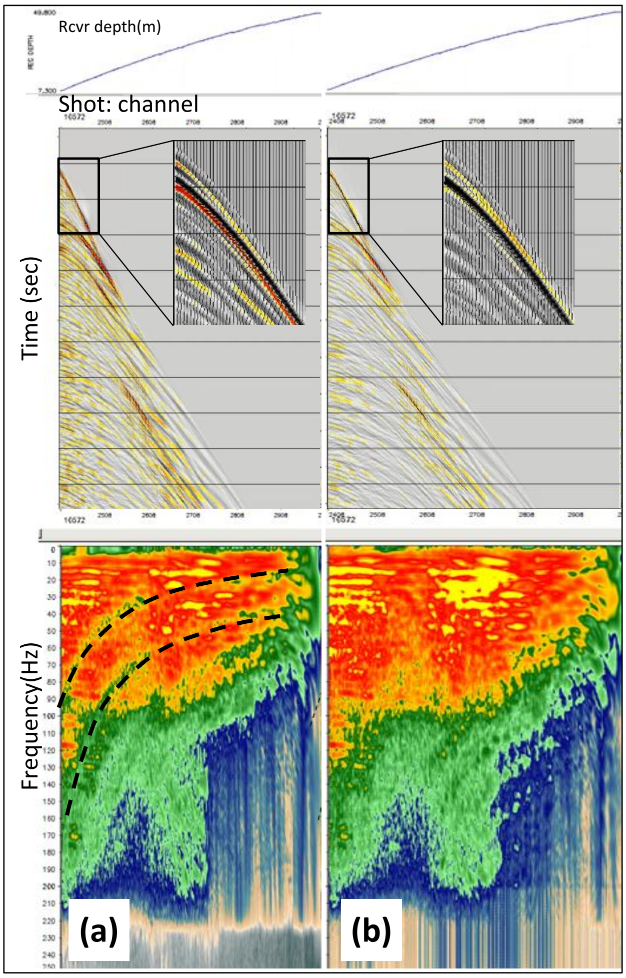

Figure 3: Shot record and f-x spectra before (a) and after (b) 3-D receiver de-ghosting. Receiver depths (7-50m) graphed above shot record. First and second order receiver side ghost notches (dashed lines) are clearly visible in the f-x display on input data. Note the variable notch frequency related to the variable streamer profile.

Multiple Modelling Method

The water-bottom in the shallow water environment of the survey area is very hard. Multiples are therefore predominantly water-layer related. The area under discussion in this paper has water-bottom depths ranging from 60 to 200m. Referring to Figure 2, the nearest channels have an offset of ~250m in the x-direction and 25 to ~525m in the y-direction. In this environment, the water-bottom reflection needed by surface related multiple elimination (SRME) to predict water-layer related multiples will not be recorded with sufficient fidelity. The large reflection angle for shallow reflectors also makes borrowing of traces with partial normal moveout (NMO) problematic for SRME. Consequently an alternative approach to multiple removal is required. Shallow water demultiple (SWD; Hung, 2011) and selective input 3-D model based water-layer demultiple (SL3D-MWD; Wang et al, 2015) are two methods used to remove free-surface multiples where water depths are too shallow to apply SRME directly.

Shallow water demultiple uses information from within the data for predicting and removing short period multiples. A model of the water-bottom and shallow reflectors is created from multiples in the data; the modelled traces are then convolved with the data to create a model of the multiples. This process is generally very effective at removing short period water-layer related multiples, however being a 2D process it has its limitations where there is a strong 3D effect due to wide tow acquisition in shallow water, especially for outer cables.

Model base water-layer demultiple predicts multiples by convolving the recorded data with Green's functions representing water-layer reflections. As we only have the reflectivity series of the water-bottom we only model water-layer related multiples, however these are usually our strongest multiples (in practice multiples can be modelled from shallow reflectors other than the water-bottom if the horizon can be accurately picked, and the RMS velocity at the horizon can be accurately estimated). 2D-MWD, like shallow water demultiple, is effective at removing most water-layer related multiples on inner cables, but suffers from the same limitations on outer cables where strong 3D effects are present. A 3D implementation of the process is required in these cases.
3D-MWD results in improved modelling of water-layer related multiples on outer cables compared to the 2D implementation, however it can sometimes have difficulty with higher order reverberations, which require a high level of inline and crossline data consistency for accurate modelling (Wang et al, 2015). The 2D implementation often models these higher order reverberations better than conventional 3D-MWD.

SL3D-MWD is an implementation of model based water-layer demultiple that combines the benefits of the 2D and 3D processes. For inner cables, the 2D implementation has most or all of the data needed for accurate multiple modelling. For outer cables, some information may be missing from 2D modelling due to the strong 3D effects, and in this case the modelling is extended to 3D in order to build an accurate multiple model. Data selection and interpolation for the 3D stage of modelling is tailored towards accurate modelling on outer cables in a shallow water environment. Figure 5. compares results from the shallow water demultiple and SL3D-MWD multiple modelling methods on inner and outer cables. The highlighted areas show that the SL3D-MWD better models shallow multiples compared to shallow water demultiple.

Selective input 3-D model based water-layer multiple modelling is very robust if the water-bottom time used in generating the Green's function is accurate. Current best practice is to use reverse time multiple migration (RTMM) to migrate the input data then pick the water-bottom on the migrated image. If the water-bottom horizon is not complex it is often sufficiently accurate to pick on an autocorrelation of the near trace data. Both methods of water-bottom picking were tested for this survey and results were very similar.

The relative strengths of the SWD and SL3D-MWD modelling methods are exploited to generate a final shallow water multiple model. The former is used at depth where the 3D effect of the wide tow acquisition is less critical, and where the modelling of other free-surface multiples in addition to water-layer multiples is beneficial at target depths. The latter is utilized in the shallow section, taking advantage of the superior modelling of outer cable data provided by the 3D implementation. Merging of the two multiple models is performed in a spatially dependent, geologically consistent manner.

The second stage of demultiple processing involves multiple modelling of longer period surface multiples not targeted by the shallow water demultiple process. These multiples are modelled using a modified 3D SRME process. Input data to this step are shots with water-layer and short period multiples removed by adaptive subtraction of the multiples modelled in the previous stage of processing. As water-layer multiples have already been accounted for, the water-bottom event is muted off on data input to 3D SRME modelling.

Multiple Subtraction Method

Adaptive subtraction of the multiple models from the input data is performed multi-dimensionally. Figure 4 shows a schematic of the modelling and subtraction steps.

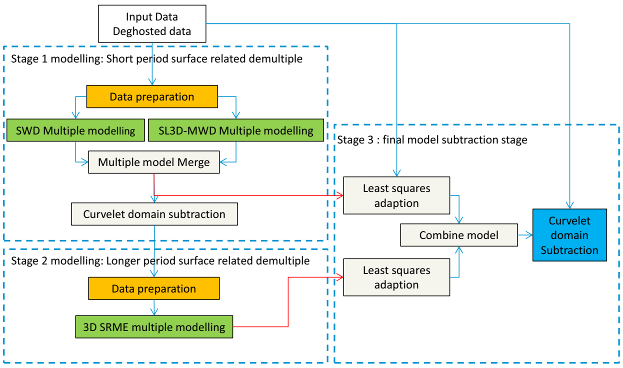

Figure 4: Multiple modelling and subtraction schematic

Global preconditioning of the merged (short period surface-related) multiple model and the 3D-SRME (longer period surface related) multiple model is performed separately using least-squares matching filtering. Data output from this process are multiple models which more closely match the phase and amplitude characteristics of multiples in the seismic data, enabling better primary/multiple separation in the final separation step. Least squares adaption is performed in frequency bands, enabling greater flexibility in handling of the frequency-dependent noise. Designing the least squares matching filter in a frequency dependent manner enables better preservation of low frequency primary energy, and better attenuation of high frequency noise.
The least squares adapted multiple models from both multiple modelling stages are combined, resulting in a final model representing all surface-related multiples. This model is subtracted from the input data using an approach based on a curvelet transform. The curvelet transform is a multi-scale and multi-dimensional transform (Candes et al, 2006) where coefficients are indexed by frequency, dip and time/space displacement. Seismic data can be well represented by curvelets as most events are either linear or curved in shape within a small spatio-temporal window (Hung et al, 2013). The additional dimensions during the curvelet transformation provide the opportunity for more accurate primary/multiple separation. Figure 6 compares input data to data processed through the full, short and long period surface related demultiple processing flow. Free-surface and peg-leg multiples (including the often difficult to remove first order water-bottom multiple) have been effectively attenuated by the combined demultiple modelling and subtraction processes.

Conclusions

It is possible to optimize the removal of shallow water multiples in wide-tow broadband acquisition data by using a combination of demultiple techniques. Water-layer multiples on outer cables where strong 3D effects are present can be accurately modelled using SL3D-MWD, a model-based multiple modelling method that uses Green's functions to represent the multiple generators of interest (typically the water-bottom). This technique is equally effective on inner cables. Water-layer multiple energy with a lower angle of incidence (deeper data) is well modelled by SWD, a 2D convolutional multiple modelling technique. Using the two modelling techniques to build a combined multiple model takes advantage of their relative strengths in the shallow and deep sections. This multiple model is in turn combined with the 3D-SRME multiple model before final subtraction from the input data.
Adaptive subtraction of the final combined multiple model from the input data is an important step in multiple removal. The flexibility of frequency-dependent least squares global adaption, used in conjunction with the accuracy of curvelet domain subtraction provides a good balance between primary preservation and multiple attenuation.

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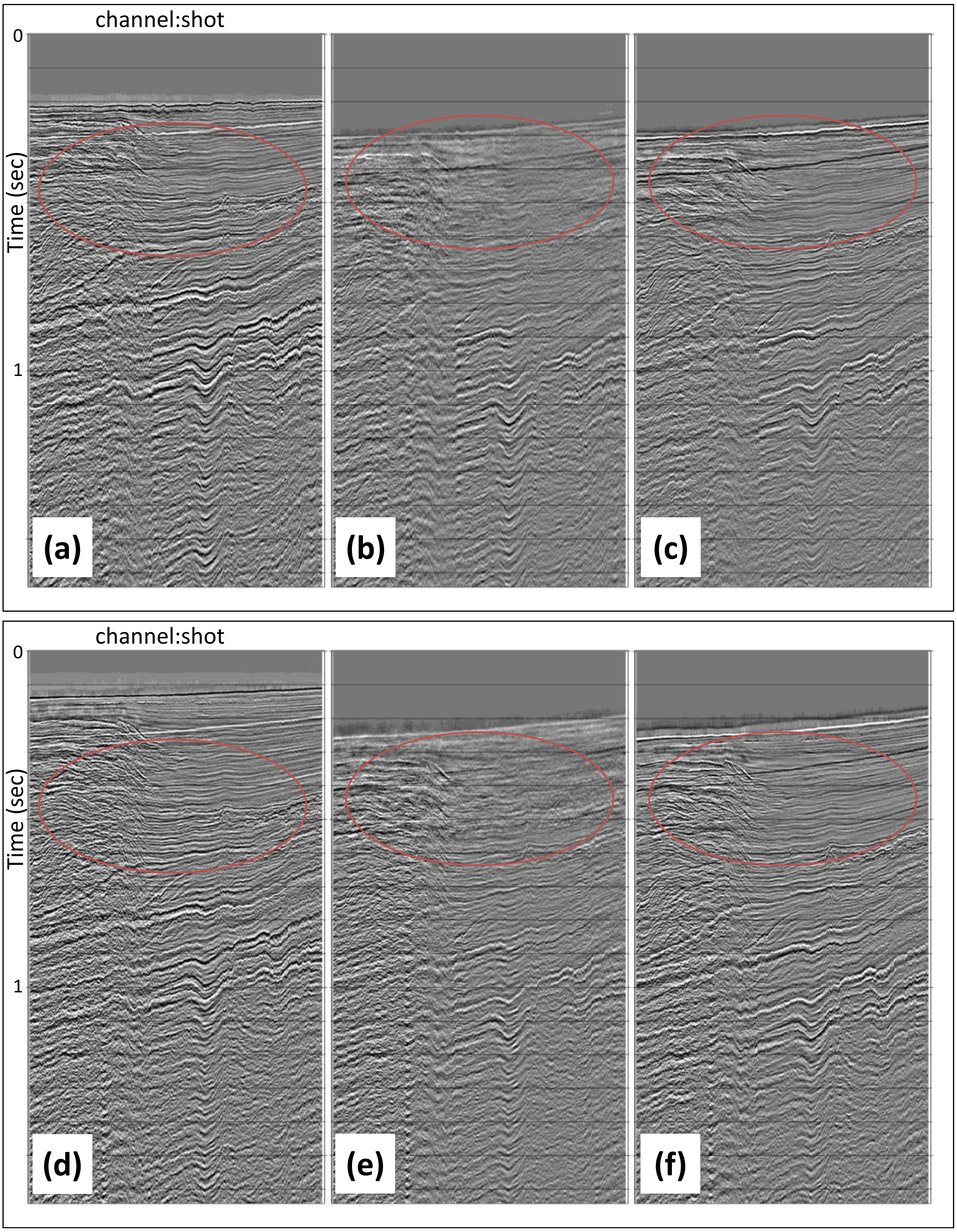

Figure 5: Multiple modelling on near channels, *outer cable*: (a): input, (b): after multiple modelling using SWD, (c): after multiple modelling using SL3D-MWD. Multiple modelling on near channels, *inner cable*: (d): input, (e): after multiple modelling using SWD, (f): after multiple modelling using SL3D-MWD. The SL3D-MWD modelling result is superior in the shallow section. SWD modelling is subtly better in the deeper section.

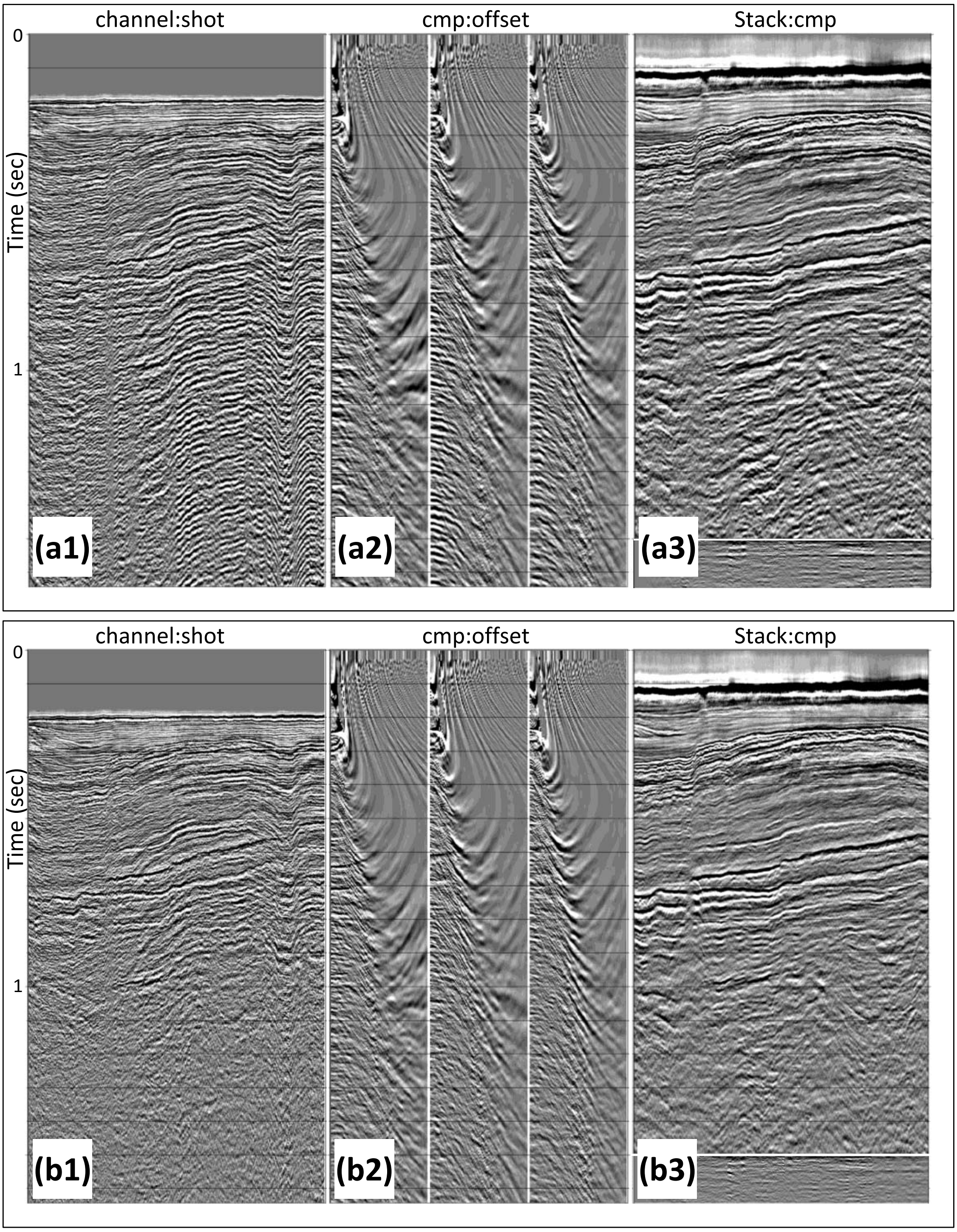

Figure 6: Demultiple result on (1) near channels, (2) cmp gathers and (3) stacks for an outer cable. Input (a) and results after shallow water demultiple using combined SWD/SL3D-MWD followed by 3D-SRME (b). Autocorrelations appended to the bottom of the stack displays (analysis window 500-3500ms).