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Application of the Frequency-Wave Number (F-K) and the Radial Trace Transform (RTT) in the Attenuation of Coherent Noise in Onshore Seismic Data

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ABSTRACT

The 2D frequency-wave number (F-K) and the Radial Trace Transform (RTT) techniques; both based on Local Wave Field Decomposition (LWD) were applied to 3D seismic data acquired from an onshore Niger delta field. The objective of the study was to attenuate coherent dispersive ground roll energy and to establish which of the techniques would attenuate the ground rolls most effectively. In applying the local wave field decomposition techniques (RTT and F-K) to attenuate coherent noise from acquired seismic data, the data was transformed into RTT and F-K domains, respectively from the conventional offset domain to attempt the separation of signal and coherent noise in this new domains, the LWD was applied and the results transformed back to the original offset domain. Results show that both techniques attenuated the coherent noise-ground roll energies appreciably. However, RTT was a better technique than the F-K for noise attenuation based on the clarity of primary events which we seek to enhance at the expense of the ground roll energy.

Key words: Radial trace transform, F-K spectrum, coherent noise, ground roll

INTRODUCTION

Onshore seismic data is commonly contaminated with coherent noise. This includes ground roll, direct waves, diffraction and multiples. These noises generally, interfere and mask the depth subsurface signal in seismic data (Linville and Meek, 1995). Coherent noise of which ground rolls is a major type is mostly a collection of surface waves generated by a seismic source. Ground rolls are the coherent noise type of interest in this study. They are a particular type of surface wave (Rayleigh wave) with high amplitudes, dispersive, low frequency and low velocity. Because of their dispersive nature, ground-roll masks shallow reflections at short offsets and deep reflections at long offsets (Claerbout, 1983; Saatcilar and Canitez, 1988; Henley, 2003).

Ground rolls could result from near surface lateral velocity variations and travel along the ground surface as well as along the boundaries of geological subsurface layers. Since the velocity of the surface waves is low compared to the velocities of the signals that have been reflected at the boundaries of the geologic layers, the reflected signals may be corrupted by the ground roll. It therefore, obscures signals of interest and degrades overall data quality in a survey. Thus, coherent noise often constitutes a serious problem for the interpretation of seismic data.

Several techniques are routinely applied in seismic data processing to attenuate coherent noise while attempting to preserve the primary signals and their amplitudes. Some of these techniques include the Radial Trace Transforms (RTT) applied by Ottolini (1979), Claerbout (1983) and Henley

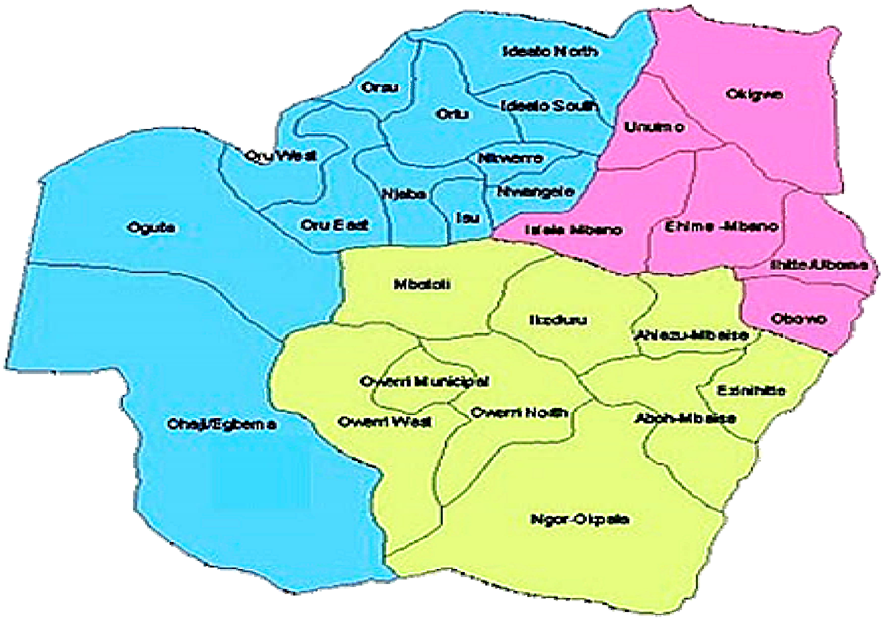


Fig. 1: Map of Imo State showing the study area

(2003); filtering in the frequency-wave number (F-K) domain demonstrated by Yilmaz and Doherty (1987) and a polarization filter approach by Tatham *et al.* (1991). These methods are based on the possibility of separating the signal and noise based on their distinguishing characteristics such as frequency content or apparent move out (Yilmaz, 1989). In this study, we seek to attenuate coherent noise from seismic data using both the frequency-wave number (F-K) and the Radial Trace Transform (RTT). We expect that both techniques would attenuate the ground roll. However, we seek to determine which of these techniques would perform optimally on an ensemble display of the same seismic shot gather.

LOCATION AND GEOLOGY OF THE STUDY AREA

The present field is located in onshore Niger Delta, South-East of Nigeria. The field lies in Ohaji-Egbema LGA, a few kilometers from Owerri in Imo State, Nigeria (Fig. 1). The Niger delta is underlain by three stratigraphic units, the deepest Akata Formation, the middle Agbada Formation and the top Benin Formation. The Benin Formation is mainly made up of continental sand deposits with intercalation of shale and is covered with topmost low velocity layer which, in most cases, is weathered within which surface waves are excited and generated. Immediately below the Benin Formation is the reservoir sand of the Agbada Formation which is believed to house the oil and gas resource of the Niger delta. The Akata Formation is also believed to be the source rock for the petroleum resource and also hydrocarbon reservoirs in deep offshore.

MATERIALS AND METHODS

The data used for this investigation is an unprocessed onshore seismic data (Fig. 2). The data is an ensemble of signals recorded from shot 102500 by different receivers in common shot configuration. The shot record as displayed is in the conventional Distance-Time domain (X-T). The

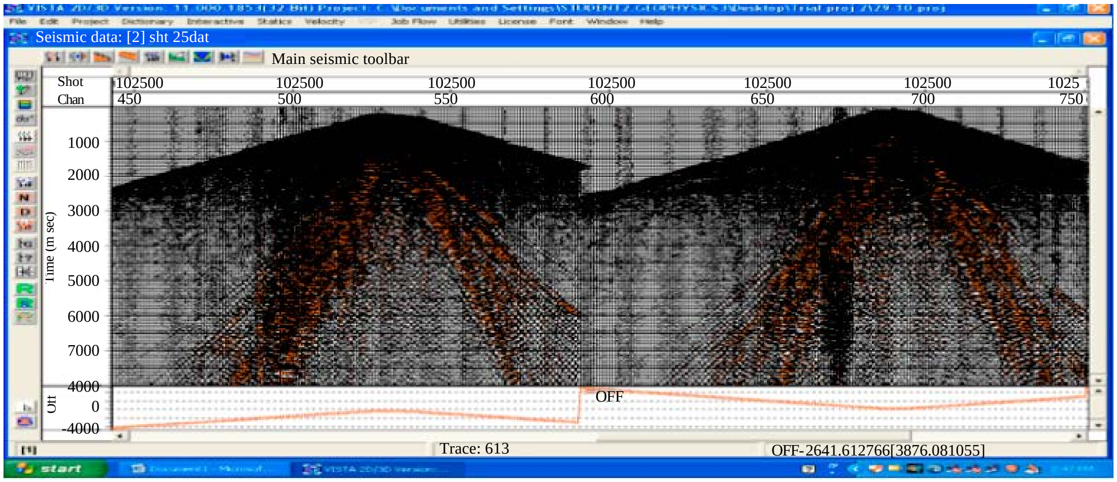


Fig. 2: Input/unprocessed data from shot 102500

full shot record is large and could not have possibly been displayed in its full length, for this reason, only a portion (or panel) from the full signal spread or ensemble was selected for this study. This shot (102500) was extracted from the full spread data by running a simple Vista flow command. The choice of shot 102500 was due to the fact that it contains significant amount of coherent noise-ground roll energy which we primarily seek to attenuate.

The methods adopted for the coherent (ground roll) noise attenuation were techniques based on the principle of Local Wave field Decomposition (LWD)-F-K and RTT.

2D frequency wave number (F-K) domain filtering: The input seismic data was transformed from the conventional t-x domain to the f-k domain by 2-D Fourier transform using a Vista software routine. The 2-D Fourier transform separates events according to their dips in the f-k domain (Yilmaz and Doherty, 1987; Zhou and Greenhalgh, 1994). A linear event f (t, x) in the t-x domain can be described by a simple equation as:

$$f(t, x) = s(t) * \delta(t - \tan(\alpha)x + b) \tag{1}$$

where, the symbol "*" denotes convolution with respect to the variable time (t), s(t) is a seismic wavelet, α is the angle between the simulated linear event and the space axis and the constant b is the intercept of the event on the time axis.

The 2-D Fourier transformed expression of Eq. 1 is given as:

$$F(\omega, k) = S(\omega)\, e^{i\omega b} \delta(k - \omega \tan(\alpha)) \tag{2}$$

where, S (ω) is the Fourier transform of the time function s(t) in Eq. 1. Equation 2 shows that any linear event in the t-x domain can be transformed into another linear event in the f-k domain. It was based on this property of the 2-D Fourier transform that a filter was designed in the f-k domain to remove the unwanted coherent noise (ground roll) from the input seismic data. A rejection zone based on frequency was defined in the f-k space within which lies the ground rolls which we seek

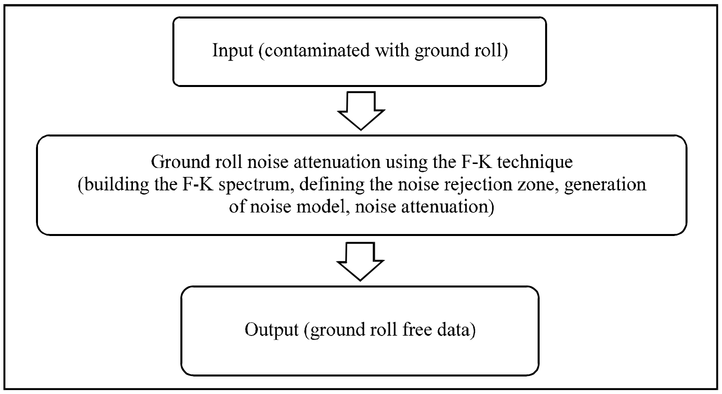


Fig. 3: Workflow for ground roll suppression using the F-K technique

to attenuate. The data in this rejection zone which we term as noise where then muted off from the f-k space and our data transformed back to the t-x domain now coherent (ground roll) noise free. The detailed processing work flow adopted is presented in Fig. 3.

Radial Trace Transform (RTT) technique: The radial trace transform is a re-mapping of the normal X-T seismic domain (with co-ordinates of source-receiver offset and two-way travel time) into a domain whose co-ordinates are apparent velocity and two-way travel time. Traces in this domain all share the same X-T origin and hence are "Radial" with respect to that origin (often the shot origin). Because the radial transform has the same time co-ordinate as the original X-T domain, the transform operation can be posed as a simple interpolation of trace samples from X-T time slices to R-T time slices. A major effect of re-mapping seismic data into the R-T domain is that linear events which have apparent velocity and origin in common with those of radial trace trajectories have their apparent frequencies dramatically lowered in the radial domain; while events, such as reflections whcih do not share apparent velocity and origin with any radial traces are unaffected (Henley, 1999, 2000).

The Radial Trace Transform (RTT) maps the amplitudes of seismic traces (S) whose coordinates are source-receiver offset (x) or some other lateral distance from a single reference point and two-way travel time (t), to the new coordinates of apparent velocity (v) and two-way travel time (t').

The transform is defined by:

$$R\{S(x,t)\} = S'(v,t') \qquad (3)$$

With the inverse given by:

$$R^{-1}\ \{S'\ (v,t')\} = S(x,t) \qquad (4)$$

Where:

$$t' = t;\ v = x/t \qquad (5)$$

The processing workflow (Fig. 4) was strictly followed for the ground roll attenuation using the RTT technique.

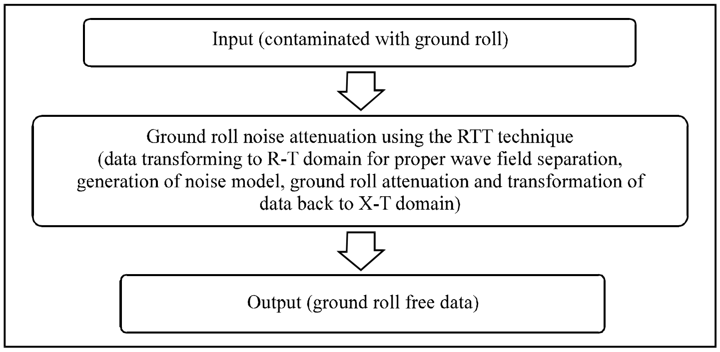


Fig. 4: Work flow for ground roll suppression using the RTT technique

RESULTS

The F-K and RTT techniques were applied to the same input unprocessed seismic data to attenuate ground rolls and enhance the primary reflections.

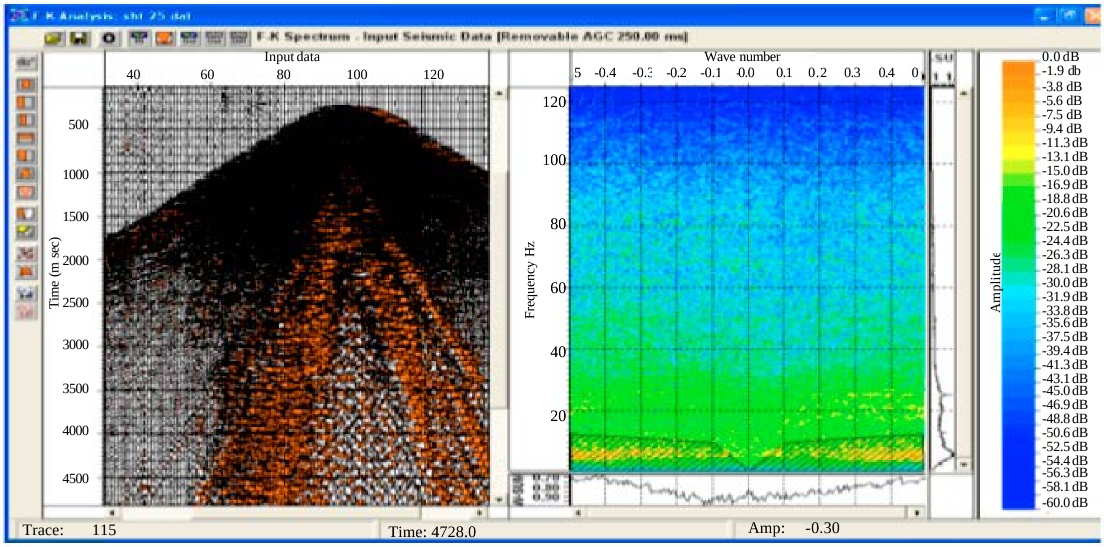
F-K 2D filter design and implementation: The optimum filter (Fig. 5) was designed in such a way as to mute the unwanted signals based on both frequency and wave number basis. This helped to preserve low frequency signals around the wave number range of -0.1 to 0.2. The filter was carefully designed so as not to totally mute off frequencies below 12.5 Hz, that is, a total horizontal mute of frequencies below 12.5 Hz. Such design would most likely have destroyed useful primary signals or data of low frequencies within the wave number (K) range of -0.1 to +0.2 which is not desirable. Results show that the 2D F-K technique was able to model the coherent noise-ground rolls (Fig. 6) However, noise attenuation were not efficient as imprints of ground rolls were still visible after the filtering operation (Fig. 7).

The RTT forward transform showed appreciable wave field separation (Fig. 8). A noise model was generated in both RT domain (Fig. 9) and X-T domain (Fig. 10) which was adaptively subtracted from the input/unprocessed data to yield our post attenuation result using RTT (Fig. 11). During the selection of amplitude scaling parameters (applying our signal band pass), we ensured that the selections were not too sharp to avoid a situation of ringing amplitudes-Gibbs phenomenon which would have ended up in adding amplitude artifacts to the input data.

From the results, it was observed that ground roll noise imprints were more effectively attenuated using the RTT technique than the F-K technique (Fig. 7-11). This could be an indication that the RTT may be a better technique to effectively attenuate coherent noise (ground roll) problems in seismic data than the conventional F-K domain filtering.

DISCUSSION

We have applied two techniques; the Radial Trace Transform (RTT) and the 2D Frequency-wave number (F-K) domain filtering for coherent noise-ground roll attenuation on seismic datasets acquired from an onshore Niger Delta field. We have shown that both methods could attenuate coherent noise as have been individually demonstrated by Yilmaz and Doherty (1987) (for filtering in F-K domain) and by Henley (1999, 2000, 2003) (for the Radial trace transform-RTT). However, in our comparative study of the efficiency of these two techniques on the same ensemble display of shot gathers we observed that coherent noise attenuation with the

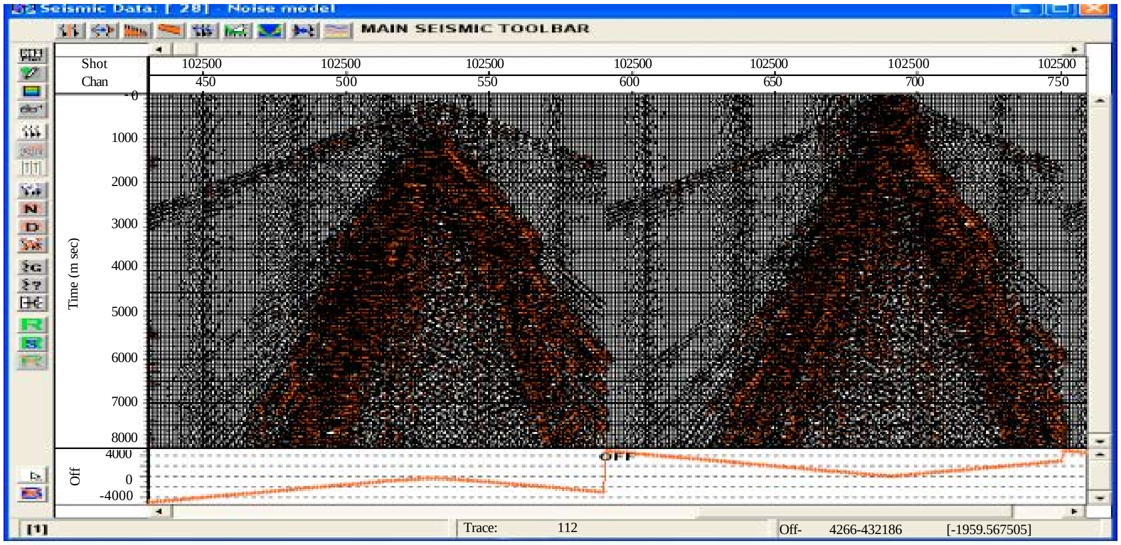


Trace: 115

Time: 4728.0

Amp: -0.30

Fig. 5: Input data (1st panel) juxtaposed with an F-K spectrum analysis window



Trace: 112

Off- 4266-432186 [-1959.567505]

Fig. 6: Noise model for the unprocessed Input data (F-K Predicted)

F-K technique still exhibited remarkable traces of coherent noise (ground roll energy) and the suppression of primary reflections on the shot gathers. However, looking closely at the result obtained from our RTT technique, the coherent noise traces were seen to have been better attenuated and the primary events enhanced. The results therefore, show that the Radial Trace Transform (RTT) technique attenuated the coherent noise better than the (F-K) domain filtering based on the clarity of the primary events on the seismic panel which we seek to enhance.

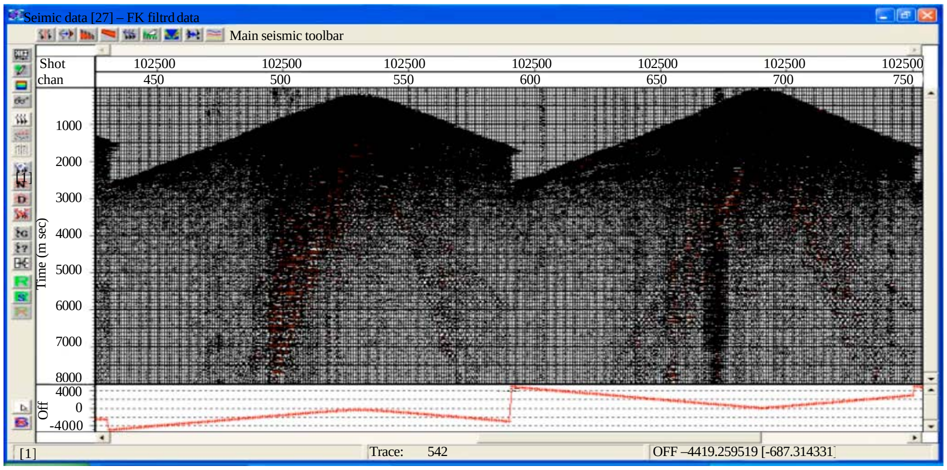


Fig. 7: Output data after coherent noise suppression using F-K domain filtering

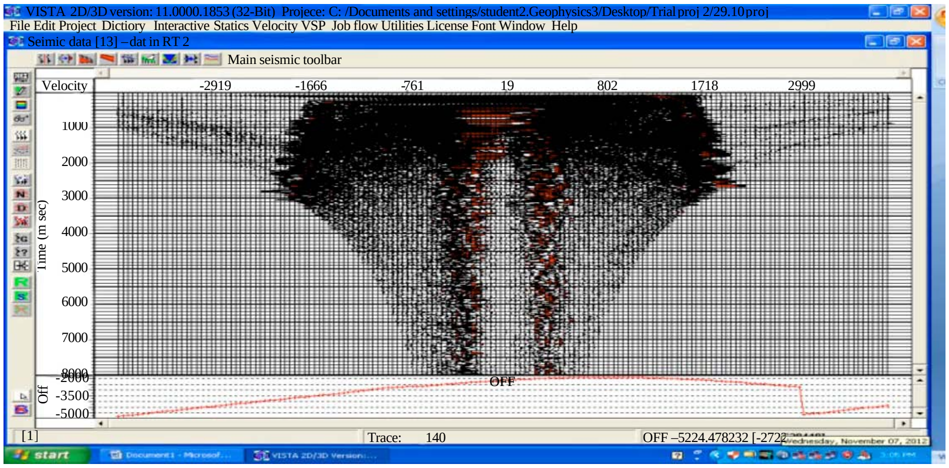


Fig. 8: Input data in the radial trace transform domain

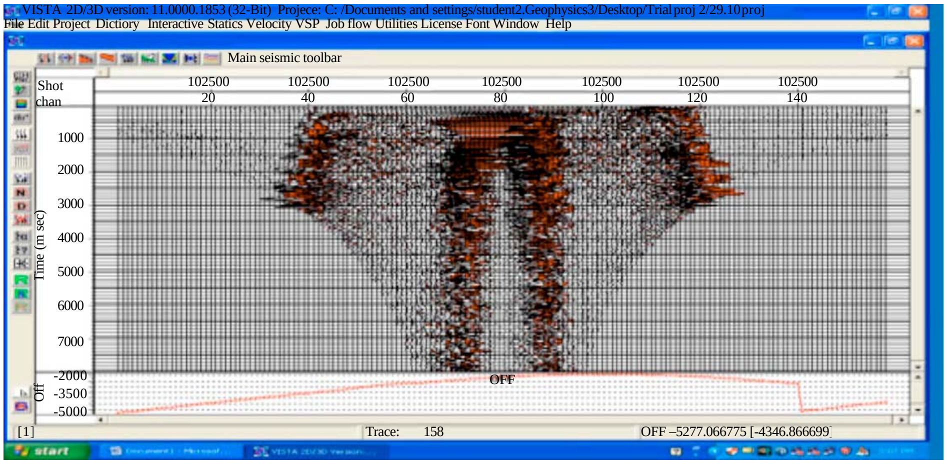


Fig. 9: Noise model for the input data in RT Domain

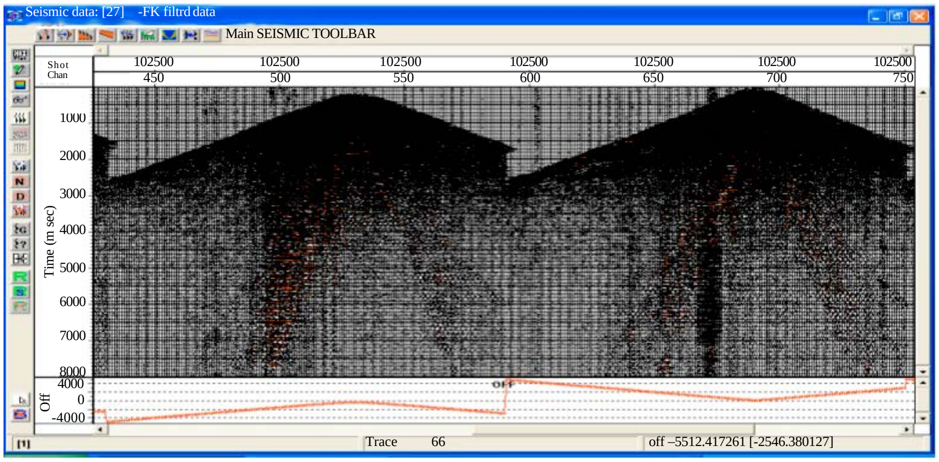


Fig. 10: Noise model transformed to the X-T domain

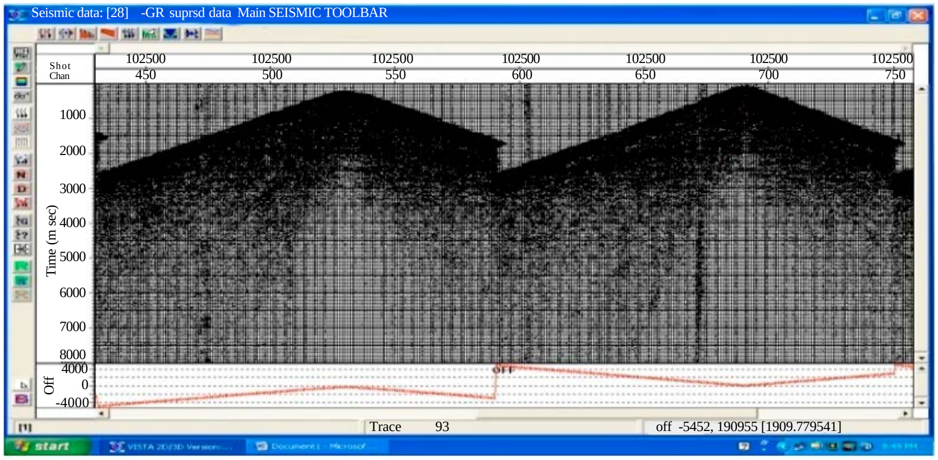


Fig. 11: Output data after coherent noise-ground roll attenuation using Radial Trace Transform (RTT)

CONCLUSION

We have applied the 2D frequency-wave number (F-K) and the Radial Trace Transform (RTT) techniques, both based on Local Wave Field Decomposition (LWD) to 3D seismic data acquired from an onshore Niger delta field to attenuate coherent dispersive ground rolls. We were able to establish that the not too commonly used Radial Trace Transform (RTT) technique is a better method for attenuating coherent noise (ground rolls) on seismic shot gathers than the conventional frequency-wave number 2D (F-K) domain filtering technique in the field.

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