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A Statistical Amplitude Analysis Method with Application to Streamer Data from the Niger Delta Offshore

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Abstract: *Multichannel processes in signal processing tend to 'smear' anomalously high and low amplitudes in the seismic data. Removal of traces with anomalous amplitudes in the earlier stages of seismic data processing is therefore expedient. In most cases, manual inspection of the gathers is carried out during trace editing, where any identified trace with anomalous amplitude is edited out from the record. Due to human error, a number of traces with anomalously high or low amplitudes are retained in the data, and this leads to a number of problems in subsequent processing, especially signal processing stages. Resolving these problems later in the processing incurs cost and leads to loss of time. We present in this paper, a global statistical approach that successfully detected anomalous traces in a streamer dataset from the Niger Delta offshore. The technique is able to flag anomalously high and low amplitude traces globally prior to signal processing, and provides an easy and quick way of removing these traces with high level of confidence.*
Keywords: *Anomalous amplitude, flag, global statistical technique, signal processing, trace editing.*

I. Introduction

Due to complexities in the field, the recorded seismic traces are often contaminated with noise, arising from human or instrumental factors, or bad weather conditions during the data acquisition. Some of the noise may appear on small groups of adjacent channels, and may be characterized by high amplitude and low frequency such as swell noise and mud roll, and others may appear as linear dipping or hyperbolic noise such as seismic interference noise. In marine or offshore acquisition, shark bites on the acquisition cables or debris striking the cables may cause low amplitude, high frequency noise which may be hyperbolic in nature and show up on small groups of adjacent channels on shots. Shorting within the cables or electrical sparks during recording may cause high amplitude spikes in the data. The high or low amplitude anomalies constitute noise in the recorded signals, and cause swinging and smearing of migrated data which would adversely affect the final subsurface image and provide wrong information for interpretation if they are not removed during signal processing of the data. Fig. 1 shows an example of common shot gather with very high RMS amplitude and normal dominant frequency. It may be very difficult in most cases to visually detect these kinds of traces and very often, most are missed in trace editing and carried along during subsequent data processing.

Removal of anomalous amplitudes from the seismic record is an important and challenging issue in signal processing. In the early years of seismic exploration, sophisticated techniques of attenuating anomalous amplitudes during processing of the data were not available, hence noise attenuation techniques were limited to the grouping of geophones to cancel coherent noise [1]; [2]; [3]. In these days of digital recording and multichannel processing, noise removal techniques rely on properties which make the noise to be distinguished from the signals. Such properties include the amplitude of a trace in some window, the decrease in amplitude with time and average period of a trace over some window [4]. Multichannel techniques such as F-K filtering [5], FX-decon [6] and t-x prediction techniques [7] largely rely on these properties to attenuate noise. Other efforts at removing noise include dip filtering, demultiple techniques , stacking and deconvolution.

The multichannel techniques for removing unwanted signals from the data are often carried out after the initial trace editing which, often times, are done by manual inspection of the data whereby any identified anomalous amplitude in the signal is removed. Due to the volume of data to be processed, especially in 3D surveys, it is practically impossible to identify all anomalous traces during manual trace editing and as such, several bad traces or traces with anomalous amplitudes are inevitably missed and retained in the data due to human error. A number of multichannel processes in signal processing utilize least-square methods in deriving filters for cleaning up the data in preparation for processes such as velocity analysis and model building, pre-stack migration and amplitude variation with offset analysis. Unfortunately, high amplitude noise causes errors in the prediction filters since they are likely to overwhelm the smaller errors that are more of interest [8]. This causes noise to be retained in the data which, if not addressed, could result in a final image not representative of subsurface structures. Fig. 1 is a common shot gather showing very high RMS amplitudes in the data, but this noise could easily be missed in editing by manual inspection.

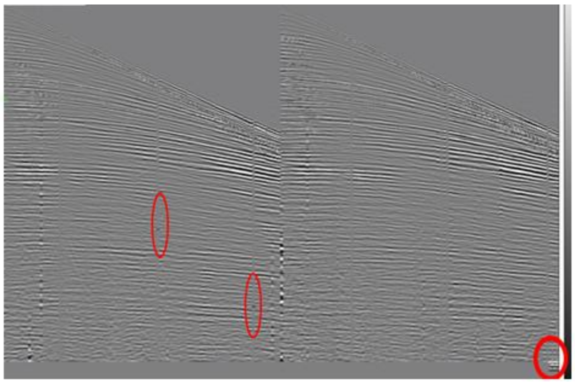

Fig. 1: CSG showing very high RMS amplitudes and normal frequency.

In this research, we used an a global statistical global approach to successfully detect and remove anomalous traces prior to signal processing stages in a 3D streamer dataset acquired in the Niger Delta offshore. This was aimed at substituting the human element in this task for greater accuracy and reduced operational time to obtain a dataset largely free from anomalous high or low amplitudes such that noise attenuation and demultiple techniques that would be performed on the data during subsequent processing would give optimum results. The intention is to calculate RMS amplitudes and the dominant frequency of each trace within a “select” window and output as header information for database displays. DB plots of the amplitudes against the dominant frequency may show up anomalous amplitudes and frequency values that point to bad traces that could be selected for automatic removal.

Location and Geology

The study area is located in the southern part of the Niger Delta offshore (Fig. 2). The Niger Delta lies between latitudes 4° N and 6° N and longitudes 3° E and 9° E, and comprises Tertiary age siliclastic deposits which range in thickness from 10 km to 12 km. The Niger Delta is divided into three lithological formations representing progradational sedimentary facies distinguished mainly on the basis of sand-shale ratio [9]; [10]; [11]. These are namely the Benin, Agbada and Akata Formations. The Benin Formation consists of massive deposits of mainly alluvial and upper coastal plain sands with a few shale interbeds. The Agbada Formation consists of alternating sandstones and shales, the upper part having more sandstone content than the lower part. The Agbada Formation represents the delta front, distributary channels and delta plain, with the sandy part being regarded as the main hydrocarbon reservoir in the Niger Delta. The Akata Formation is the basal unit of the Tertiary Niger Delta complex, and is composed predominantly of medium to hard, dark grey shales with plant remains especially at its upper part. Sedimentation in the basin began in the late Paleocene /Eocene, when sediments commenced to build out ahead of the troughs between the basement horst blocks at the northern flank of the present delta area. The structural pattern and the stratigraphy of the Niger Delta have been controlled by the interplay between rates of sediment supply and subsidence [12]; [9].

The primary seal rock in the Niger Delta is the interbedded shale within the Agbada Formation. The shale provides three types of seals - clay smears along faults, interbedded sealing units against which reservoir sands are juxtaposed due to faulting and vertical seals [9].

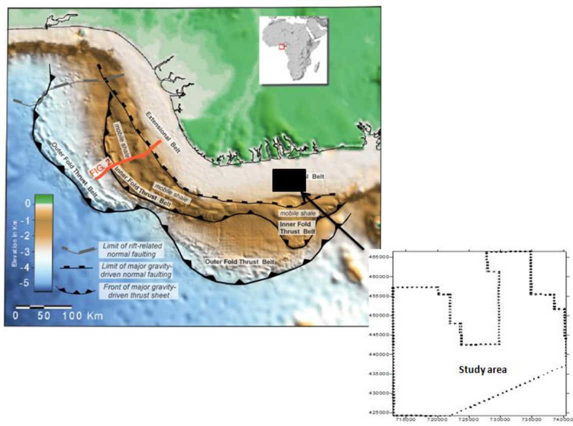

Figure 2: Map of the Niger Delta showing the study area. Major structural features of the delta are labeled shown over a bathymetric map from [13] (modified from [14].

II. Materials and Methods

The main objective of this research was to develop a global statistical amplitude analysis technique capable of flagging all anomalous high or low amplitudes in pre-stack seismic data in the early stage of the data processing, in order that subsequent processing algorithms performed on the data would give optimum results. In the first instance, we performed trace editing using ProMAX, to drop dead and corrupt traces from the data, as well as traces with LMO problems, auto- and mis-fires as given by the observer's report. The global statistical trace editing method requires the start of trace amplitude and frequency calculations to be hung from the water-bottom. In order to achieve this, we converted cable depths from shots to time using Equation 1:

$$T_{p1/90} = \left[\frac{D_S}{V_W} \right] \text{x } 2 \text{ x } 1000 \text{ ms} \qquad 1$$

where D_S is shot depth and V_W is water velocity. Amplitude and frequency calculation was then hung from the top at $T_{p1/90} + 200\text{ ms}$ (Fig. 3).

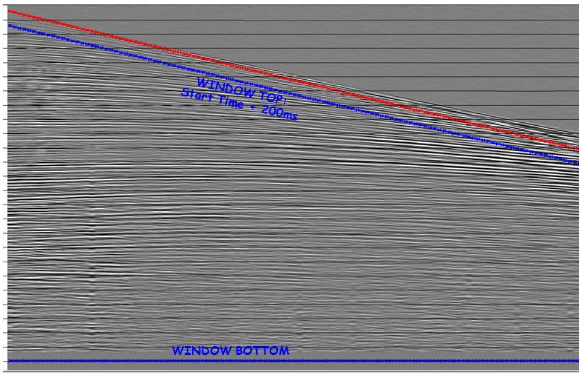

Fig. 3: Global amplitude analysis window

Trace statistics was then performed whereby on every trace and over the whole analysis window, measurement of the dominant frequency and RMS amplitudes was done, and values stored in the trace header. Trace statistics computes the energy envelop of each trace from the trace and its Hilbert transform. The complex seismic trace is given by Equation 2:

$$\Psi(t) = f(t) + i\,h(t) \qquad 2$$

where $f(t)$ is the real part and $h(t)$ is the imaginary part. $h(t)$ is the Hilbert transform of $f(t)$, also known as the quadrature function of f(t) [15], and is given by Equation 3:

$$h(t) = \frac{1}{\pi} \text{P.V.} \int_{-\infty}^{\infty} f(\tau) \frac{1}{t - \tau} d\tau \qquad 3$$

where P.V. is the Cauchy principal value. $f(t)$ and $h(t)$ are related in such a way that together, they form an analytic signal having an amplitude and a phase where the derivative of the phase gives the instantaneous frequency. In a very simple form, the amplitude and phase of the analytical signal (Equ. 2) are obtained as follows:

$$\text{Amplitude,} \quad a(t) = \sqrt{f^2(t) + h^2(t)} \qquad 4$$

$$\text{Phase,} \quad \phi(t) = \left[\frac{h(t)}{f(t)} \right] \qquad 5$$

and if the frequency, f, is not constant but slowly varying, then the instantaneous frequency is the time derivative of the instantaneous phase, and is given by Equation 6 as follows:

$$f = \left[\frac{d(\phi(t))}{d(t)} \right] \qquad 6$$

Lastly, we created a geometry database with the calculated amplitude/dominant frequency, re-gridded the geometry to 0.5 m x 0.5 m cell increment from the original grid of 12.5 m x 25 m, and each trace was put in a bin, based on the calculated amplitude and dominant frequency, with each bin retaining a count (or fold) of the number of traces in that bin. This was done to reduce the header dataset of millions of traces to something that could be plotted in a single plot. The binned dataset was then written to a database and a global plot of amplitude versus frequency was made, based on the number of counts of traces in each bin (trace fold). This plot was achieved by setting cdp_x = binned frequency, cdp_y = binned RMS amplitude and the Z axis as the binned trace count or fold.

III. Results and Discussion

Fig. 4 shows global statistical display of RMS amplitude versus dominant frequency of the binned traces. It is easy to identify the anomalous amplitudes on the display. These are selected and flagged for removal by application of a polygon as shown. The technique is able to reveal a clear cut-off between useful and anomalous amplitudes in the data. Application of the polygon as a selection criterion makes it possible to remove all data with anomalous amplitudes with confidence through visual inspection of the global plot of the traces. Fig. 5 shows the same plot after application of the selection polygon to remove the anomalous amplitudes from the data.

RMS timeslice at 3 sec to 5 sec window is shown in Fig. 6. It is evident from Fig. 5 and Fig. 6 that there is residual noise in the data after the statistical editing. This noise is as a result of noise which was not targeted in the global noise removal technique described in this work. The non-targeted noise include swell noise and linear dipping noise, and there are well known standard swell denoise and radial noise filtering techniques for removal of such noise. These denoise techniques which are carried out in the later stages of the processing would greatly benefit from the method presented in this work, since the anomalous amplitudes that could affect the denoise prediction filters at such stages would have been removed by the global statistical editing. This would also cause a lot of time to be saved during testing of filter parameters for subsequent processing algorithms.

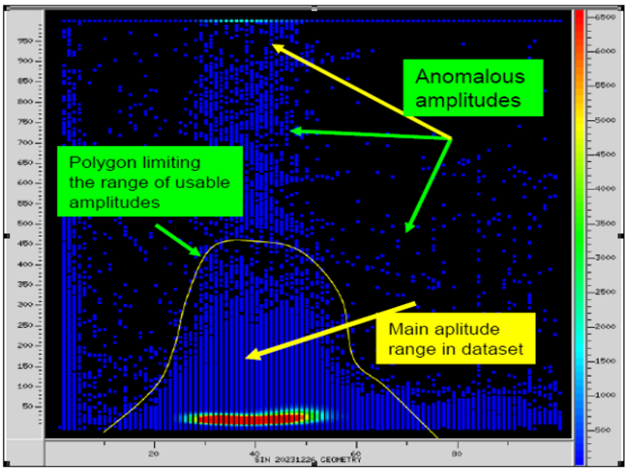

Fig. 4: Global statistical display of RMS amplitude versus dominant frequency.

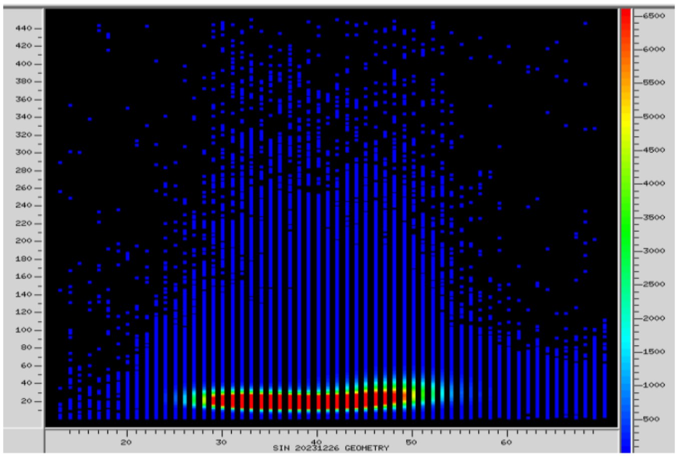

Fig. 5: Global statistical display after application of selection polygon.

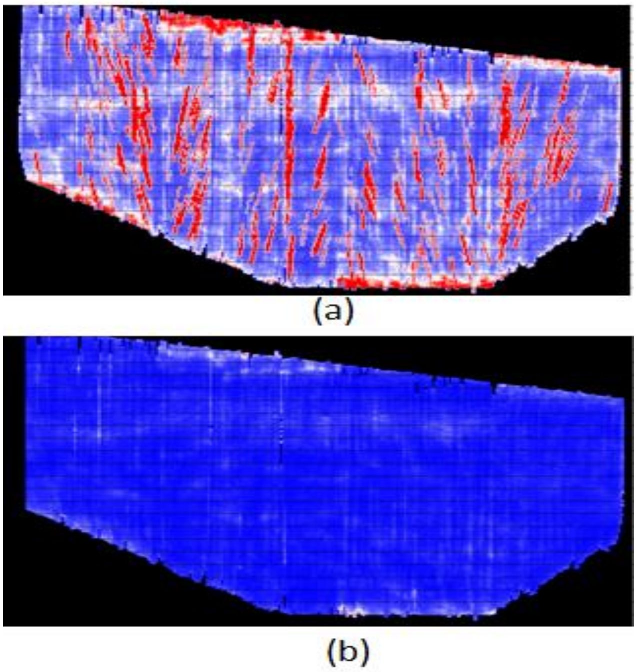

Fig. 6: RMS timeslice (a) before and (b) after global/statistical edit.

IV. Conclusion

Anomalous amplitudes due to noise will inevitably be present in seismic data acquired for exploration purposes. This is a problem and as it cannot be avoided; the only thing that can be done is to fix it during processing of the acquired data. The issue addressed in this paper is the automatic detection and elimination of anomalous amplitudes in common shot gathers early in trace editing in such a way that CPU time and error due to human intervention are minimized. This paper does not intend to address standard noise attenuation techniques which would need to be carried out after trace editing. The method presented is able to flag anomalous amplitudes which are then selected for removal from the data. It is practically impossible to remove all anomalous amplitudes if only manual inspection of the data is carried out in trace editing. The global trace editing method is expedient as anomalous amplitudes missed in manual editing could cause serious problems in subsequent processing that would be very costly to resolve.

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