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Near-Surface Data-Driven Methods for Surface Wave and Multiple Removal, Onshore Kenya

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Summary

Land surface seismic data are usually strongly affected by the presence of surface waves (ground-roll), which can completely obscure the underlying primary reflection signal. It is therefore crucial to isolate the reflection signal for both imaging and amplitude analysis needs. Complex near-surface conditions complicate ground-roll attenuation and may introduce other sources of noise such as multiples. We present an application of interferometric ground-roll removal and 3D convolutional de-multiple methods on a seismic dataset acquired onshore North Kenya, where the shallow subsurface is characterized by strong heterogeneity, caused by the presence of a fast volcanic layer and structurally complex geology. Effective removal of the unwanted surface-wave and multiple energy was achieved with minimal impact on the amplitude character of the primary reflection signal.

Introduction

In the context of land seismic acquisition, near-surface conditions can strongly impact the imaging of deeper targets and the analysis of representative reservoir attributes. In particular, surface waves, commonly referred to as ground-roll, are confined to the shallowest few hundred meters and can contaminate vast parts of the seismic records, obscuring the underlying reflections. Other well-known issues include back-scattered noise, statics, amplitude and wavelet stability, etc.

In this work, we have focused on data-driven methods to attenuate surface waves and multiple energy from a seismic dataset acquired onshore Northern Kenya, where the shallow subsurface is characterized by strong heterogeneity and structural complexity.

Large variability in the physical properties of the shallow subsurface distort or change the wavefield kinematics. For example, structurally complex geology and strong velocity variations can alter the linear character of the surface waves, and the presence of harder rocks or velocity inversions can generate strong multiples.

This wave field distortion can limit the effectiveness of de-noise techniques which rely on filtering the noise in a transformed domain (model-driven methods), such as dip filters in FK or linear Radon for ground-roll removal. As a consequence, the more complex the near-surface is, the more difficult it is to filter unwanted noise with model-driven techniques which do not account for spatial variability of the subsurface velocity.

The study area covers a basin of the Great East African Rift system, which is characterized by an asymmetric half graben structure confined by a main bounding fault on its western margin and a horst system on the eastern side. The infill consists of a sequence of Oligocene to Miocene sedimentary rocks, with one major interval of volcanic rocks.

A representative E-W section of the geological structure and seismic appearance is illustrated in Figures 1a and 1b. Figure 1c shows a seismic time slice (t = 380 ms) with the velocity model derived from refraction tomography, converted to time, overlaid. The velocity clearly captures the seismic amplitude variations and follows the near surface geology of the region. High velocity patches are evident on the western side of the area, due to the metamorphic basement, and on the eastern side, where volcanic layers outcrop. Overall, the survey area is characterized by a highly variable near-surface geology, resulting in a strong variation of linear noise character and velocity.

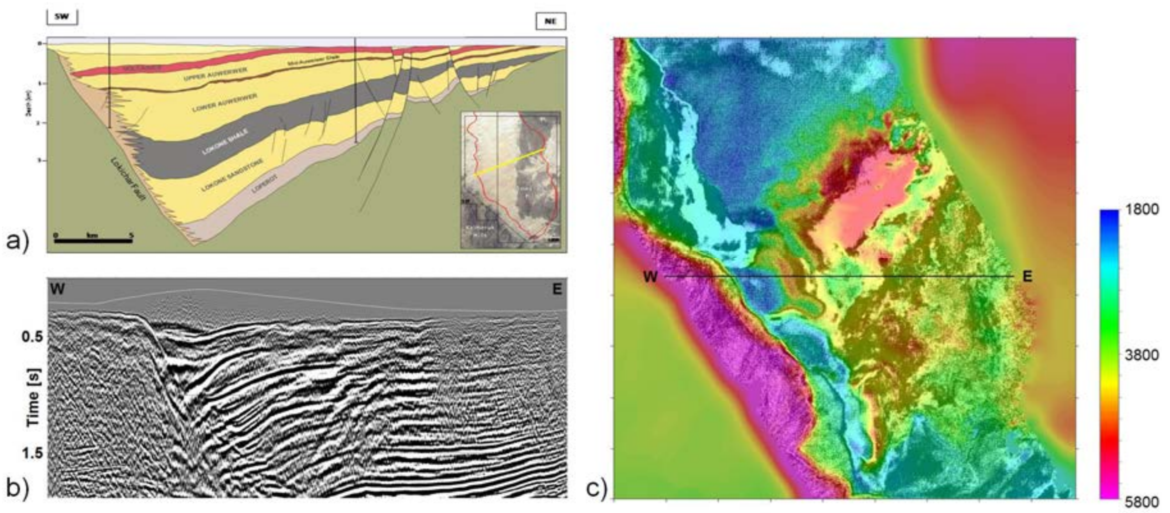

Figure 1 *Geological overview: a) Representative geological section of the survey area, South Lokichar Basin. b) Representative W-E seismic section. c) Seismic time slice (t = 380 ms) overlaid with refraction model converted to time.*

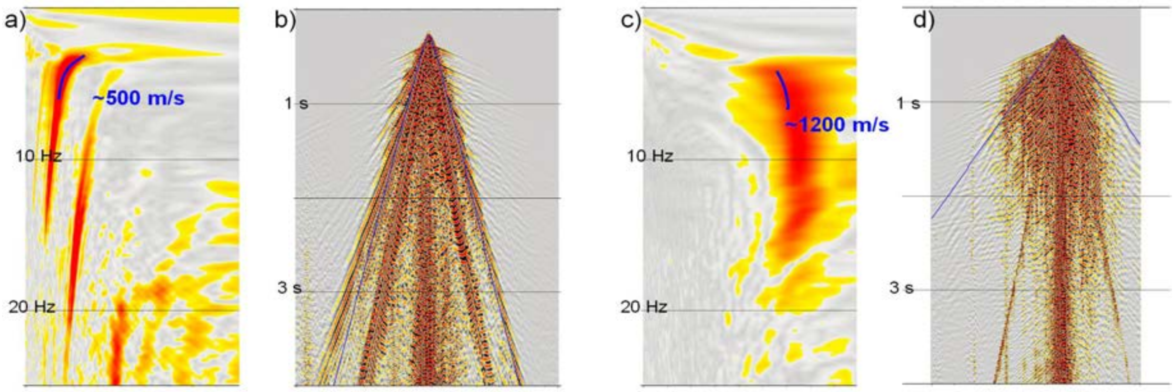

Figure 2 *Phase velocity spectra (phase velocity versus frequency) and shot gather at location A (a,b) and B (c,d) annotated in Figure 3b.*

Interferometric surface wave removal

Dispersion curves of the most energetic component of the surface waves, the fundamental mode, were analyzed and extracted across the entire survey using super-gathers of multiple source and receiver traces. Examples of shot gathers and related phase velocity spectra at two different locations show the variability of the surface wave character and the impact of the related ground-roll cone on the primary reflections (Figure 2). Since the penetration depth of surface waves is inversely proportional to the frequency and is sensitive to shear wave velocity, frequency slices of the phase velocity correspond to depth slices of shear velocity. The phase velocity at 6 Hz was compared to the average velocity of the first 150 m of the refraction tomography model (Figures 3a and 3b). A remarkable match was observed, confirming the robustness of the surface wave analysis. This similarity was observed also in section view (Figures 3d and 3e).

An interferometric method described by Corentin et al. (2017) was used to attenuate the most energetic component of the surface waves, the low frequency Rayleigh waves. The method is based on source-receiver interferometry (Curtis and Halliday, 2010). The source-receiver Green’s function of the surface wave is estimated by using only energy recorded at a surrounding boundary of receivers and a surrounding boundary of sources. This confined energy is computed by integrating the cross-correlation or convolution of wave field pairs over the boundary. As sources and receivers sit on the free surface, the Green’s function estimate is dominated by surface waves.

Prior to interferometry noise modeling, a multi-dimensional reversible irregular-to-regular interpolation algorithm was applied in the cross-spread domain (Poole, 2010). The algorithm regularizes and increases the density of source and receiver geometry, enabling the aliased and the non-linear shape of the ground-roll to be taken into account more effectively. The surface wave model is then adaptively removed from the original data. The velocity estimates derived from the surface wave analysis were used to optimize the interpolation and the subtraction of the surface wave model.

Figure 4 demonstrates the application of the data-driven method to a far-offset shot gather, where ground-roll appears to be non-linear and conventional methods fail to preserve the true amplitude character of the primary signal. The adopted method, instead, captures the non-linear character of the ground-roll with minimal impact on primary signal. This is particularly evident at the apex of the ground-roll.

Multiple removal using 3D SRME

Next, a 3D data-driven flow based on a SRME (Surface Related Multiple Elimination) method for land data (Wang, 2014) was adopted to address surface multiples generated by the volcanic rocks. These processes were applied after linear and random noise attenuation. Least-squares subtraction was used to adaptively remove the multiple model from the original data. Alternative Radon-based methods were tested but were not effective in removing multiples in the near-offset range. Figure 5 shows the input dataset, where clear multiple energy crosses primary events, the 3D SRME output and the multiple model.

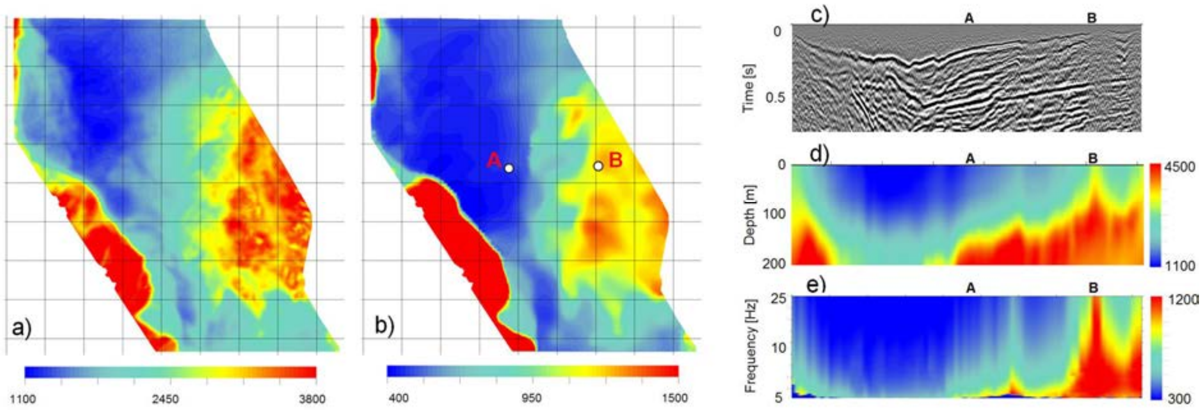

Figure 3 *Map view: a) P velocity derived from refraction tomography; b) Rayleigh-wave phase-velocity of fundamental mode at 6Hz. Section view of the line crossing points A and B: c) raw seismic filtered and scaled; d) refraction tomography model; e) phase-velocity distribution of fundamental mode, pseudo-depth section.*

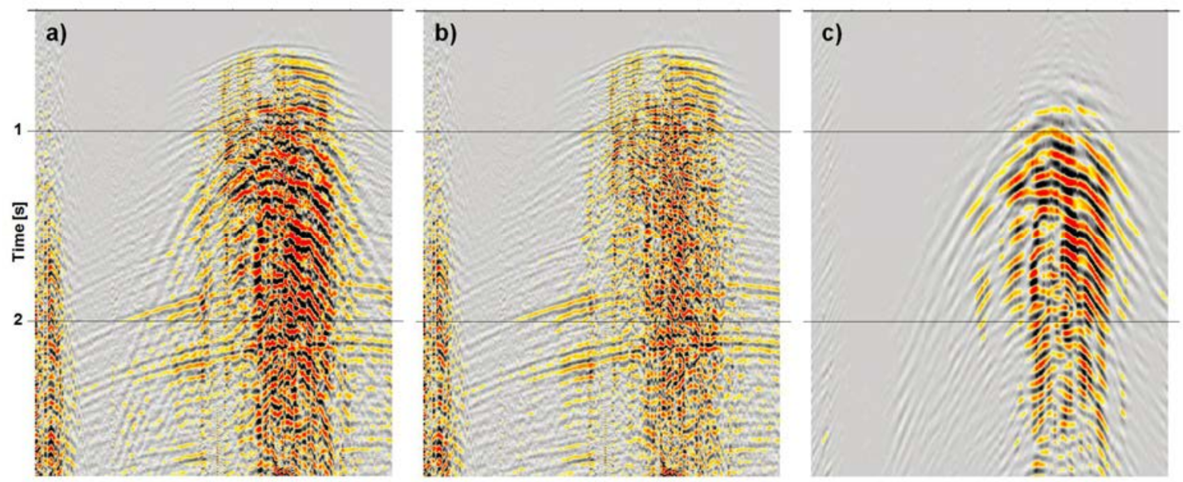

Figure 4 *Shot gathers: a) input data; b) surface-wave driven interferometry output; c) noise model.*

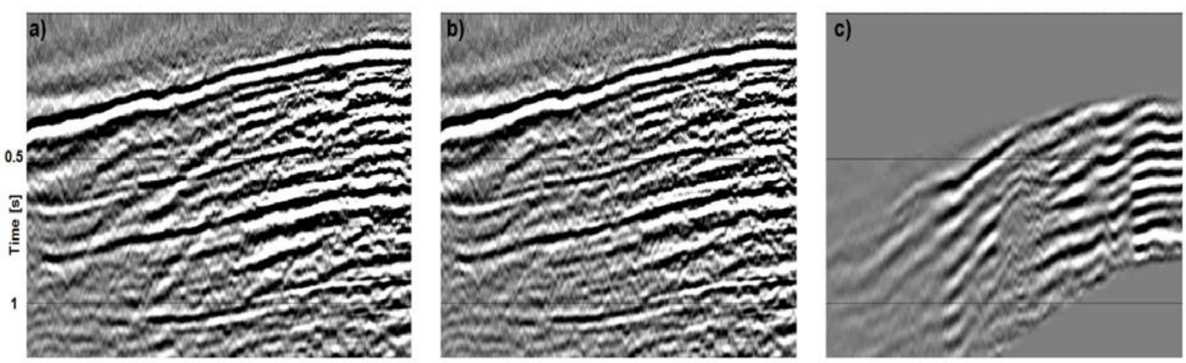

Figure 5 *Stack section: a) input data; b) data-driven de-multiple output; c) multiple model.*

Data comparison

Following the noise attenuation, the data were passed through a controlled amplitude processing sequence. Figure 6 shows a PSTM comparison between the legacy and the re-processed sequence. In the re-processed sequence, the fault system appears better imaged and the sedimentary package in the basin is less contaminated by multiples and surface wave noise.

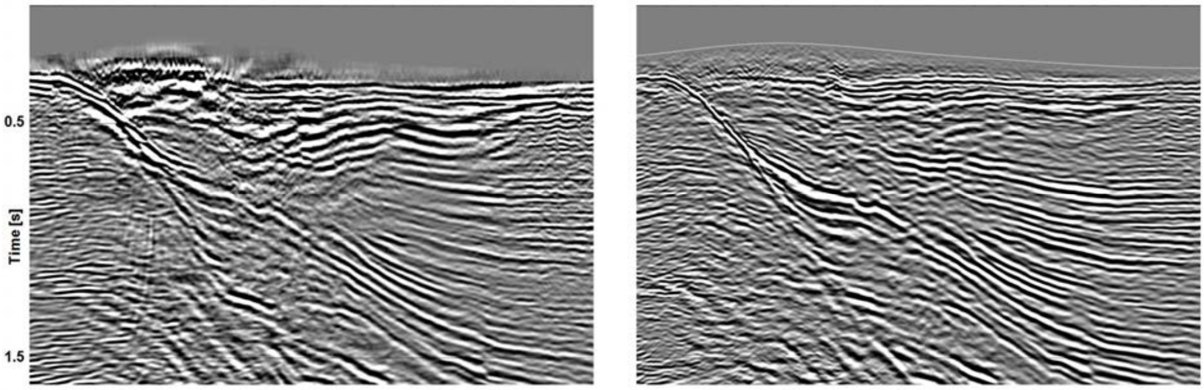

Figure 6 *PSTM example: a) legacy; b) preliminary re-processed sequence.*

Conclusions

Data-driven methods were applied to deal with the processing challenges posed by complex near-surface geology, which resulted in strongly distorted surface waves and volcanic generated surface multiples. An interferometric method was used to attenuate the most energetic component of the surface waves, and a 3D convolutional method was used to suppress the volcanic generated multiples. Effective removal of the unwanted surface-wave and multiple energy was achieved with minimal impact on the amplitude character of the primary reflection signal.

Acknowledgements

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