Correlation structure of submarine landslide deposits from seismic reflection images

J. Ford[1], P. Cance[1], A. Camerlenghi[1]

[1] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Trieste, Italy

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Extended summary

We propose a method to extract subsurface correlation lengths from "chaotic" seismic reflection images of submarine landslide deposits. The method inverts for the second-order image statistics (2-D autocorrelation function) of the chaotic zone by forward modelling an ensemble of stochastic models of slide heterogeneity. This builds on previous work in the hydrological community to characterise scale lengths in heterogeneous near-surface deposits using ground-penetrating radar reflection images (Irving et al., 2009). We generalise this technique to better account for uncertainties introduced by a complex overburden, scattering and seismic processing and migration.

The geohazard from slope failure is significant but currently poorly understood. Many studies use geophysical images of ancient submarine landslide deposits to inform present day hazard to seafloor infrastructure and to coastal populations from tsunami. Key parameters for such studies are the degree and type of internal deformation from sliding. This helps to constrain slide dynamics – for example slide velocity and the degree of frontal confinement – important for proper numerical modelling of slide runout and tsunami generation.

Reflection images of submarine landslides often show a characteristic "chaotic" texture (disordered, incoherent reflections) because the scale of structures inside the slide are around or below the seismic resolution (Chopra and Marfurt, 2016). This is in part due to strong stratal disruption caused by deformation during sliding, which acts in particular to reduce lateral scale lengths with respect to unfailed sediments. The lack of coherent reflections makes traditional seismic interpretation techniques such as horizon picking difficult or impossible (Figure 1).

Here the subsurface velocity structure of submarine landslide deposits is described by two components: 1) a deterministic "background" component, with slowly varying velocity and density and 2) a stochastic component, with relatively small velocity pertubation from the background. We assume that the stochastic component can approximately represent the heterogeneity inside submarine landslide deposits from stratal disruption. For this study we also assume that the heterogeneity approximates a random medium with exponential, anisotropic spatial correlation and zero-mean Gaussian distribution of velocity pertubations. Under these assumptions, if the seismic image approximates a zero-offset primary reflectivity section then the autocorrelation function of the image should approximate the autocorrelation of the subsurface velocity structure convolved with the autocorrelation of the source wavelet in depth, with a correction for the lateral resolution of the migrated section (Irving et al., 2010). This method seeks to characterise the medium by inverting the chaotic zone in the seismic image for vertical and lateral correlation lengths (Figure 2). These parameters can characterise the degree and type of internal deformation from sliding.

As found by Irving et al. (2009), the inversion is poorly constrained for vertical correlation lengths due to the "vertical derivative" effect of the seismic wavelet in surface reflection experiments. However, the aspect ratio (lateral correlation length divided by vertical correlation length) is relatively well constrained. If vertical correlation length can be estimated from downhole data (eg Cheragi et al., 2013) then absolute lateral correlation length can be calculated.

We demonstrate this technique using a synthetic benchmark. We build a sigmoidal submarine slope model (5000 m x 400 m) containing a buried submarine landslide. The synthetic seismic image is produced by 2-D visco-elastic forward modelling with a marine multi-channel acquisition geometry (maximum offset 1000 m, shot spacing 25 m), followed by a standard marine processing flow and a depth migration. We also apply the method to a real seismic image from the Nankai Trough, offshore Japan, close to where IODP borehole C0018 penetrates a thick mass-transport deposit (Figure 1).

Future development of this method should include a more robust Baysian framework for inversion, 3-D autocorrelation matching, accounting for preferential dip of the stochastic zone and proper integration of co-located geophysical methods (eg high-frequency sub-bottom profiles and borehole logs). It is hoped that estimating correlation lengths inside submarine landslide deposits will become a standard tool to better constrain the slide dynamics and thus geohazard potential of submarine landslides.

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Figures

Figure 1: Seismic profile extracted from a 3-D seismic volume acquired in Nankai Trough, offshore Japan. This profile intersects an exceptionally thick submarine landslide deposit (Strasser et al., 2011). The “chaotic” seismic texture of the slide deposits prevents confident interpretation of internal structure by horizon picking.

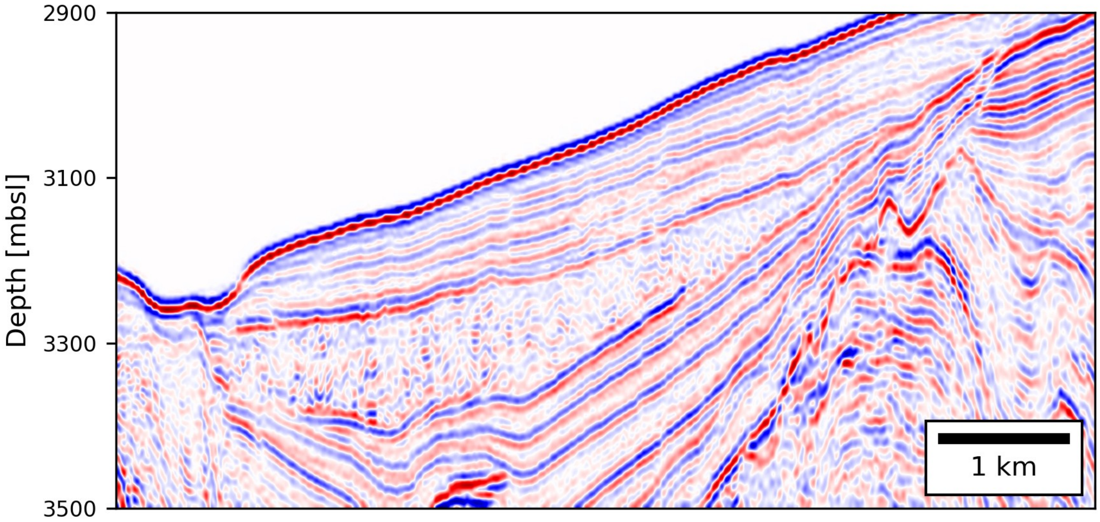

Figure 2: Flowchart showing i) generation of candidate models for the stochastic zone from the 2-D autocorrelation function (ACF), here parameterised by the lateral and vertical characteristic scale lengths (a_x and a_z); ii) integration of deterministic and stochastic components of the model onto a spatial grid; iii) seismic forward modelling, processing and imaging; iv) extraction of relevant chaotic zone from modelled seismic image and v) comparison of autocorrelation functions of modelled and observed chaotic zones. Models which meet the acceptance criteria are considered "plausible" for the observed data and their parameters are added to the output ensemble.