2013 SCEC Project Report

Toward Implementation of a Stochastic Description of Fine Scale Basin Velocity Structure in the SCEC Community Velocity Model (CVM-H)

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Abstract

This work aims to develop and implement a stochastic description of fine-scale velocity structure in the SCEC Community Velocity Models (CVMS and CVMH). The trend of numerical wave propagation studies to higher frequencies (> 2 Hz) has been facilitated by sustained increases in computational power, and has created a demand for higher resolution velocity models (e.g., Olsen and Jacobsen, 2011; Taborda and Bielak, 2013; Cui et al., 2013; Olsen et al., 2013). Building such models is challenging, in part because geologic and seismologic data indicate that fine-scale elastic inhomogeneities can be strong in sedimentary basins and have spatially anisotropic statistical distributions (Magistrale et al., 1996; Süss and Shaw, 2003; Brocher, 2005; Plesch et al., 2011). While we have local measures of fine-scale velocity structure (down to meter scales) along boreholes with sonic logs, there is not a sufficient density of such samples to facilitate the development of a deterministic regional model. Thus, we are developing a statistical description of fine-scale velocity structure, informed by these local observations and geological correlations, to enhance the community models so that they can support higher-frequency simulations. Our current results define the standard variation (6.5%) in velocity that is represented in the wells but not the current CVM-H, and show that this variation is markedly non-Gaussian. In addition, we define vertical and horizontal correlation lengths for velocity structures within the sedimentary basin of 80 and 2000 meters, respectively. Our goal is to use these characteristics to implement a fine-scale velocity structure in the CVM-H to support wave propagation and strong ground motion simulations to higher frequencies.

Technical Report

Introduction

This past year, we have analyzed wells across the Los Angeles basin and characterized the vertical variability in fine-scale velocity (Vp) structure. This analysis shows that the variability in fine-scale velocity structure has a distinctly non-Gaussian distribution. In addition, we have examined velocity structure in a large oil field in the southwestern Los Angeles basin using an incredibly dense sample of logs in deviated wells and 3D seismic reflection data (Figure 1). This study has confirmed the non-Gaussian distribution of velocity variability and the vertical correlation lengths for Vp structure on the order of 80 m. Further, this dense data sample suggests that horizontal correlation lengths are about 25 times that of vertical correlation lengths, defining the highly anisotropic nature of basin velocity structures. Finally, we show that lateral velocity structures are more highly correlated along stratigraphy than in the horizontal dimension in areas of dipping beds. This suggests that stratigraphic horizons may provide a means to guide the implementation of a stochastic description of fine-scale velocity structure in the basin models. In the current year, we anticipate extend our analysis to a set of Vs logs to assess if velocity variability is consistent with that observed for Vp. This will involve the analysis of several dipole sonic logs that constrain both Vs and Vp structure. In addition, we propose to investigate the cause of the non-Gaussian distribution of velocity variability. We suspect that this relates to the nature of the depositional sequences in the basin, and thus will examine other logs types (gamma ray, spontaneous potential, resistivity), that provide indications of lithology that can be compared directly with Vp and Vs measurements. A key objectives is to develop a geologically informed statistical model of the non-Gaussian velocity variability that can be used to understand the scattering of seismic waves in the near-surface environment. If we are successful, we will explore the implications of this model for small-scale variability of seismic hazards in sedimentary basins.

This project represents a collaborative, multi-disciplinary effort involving a seismologist with extensive experience in wave propagation and stochastic representation of velocity structure (Jordan) and the primary developers of the CVMH and its sonic log database (Plesch & Shaw). We will be assisted by USC graduate student, Xin Song, who is working on this problem as part of her PhD research, supervised by Jordan.

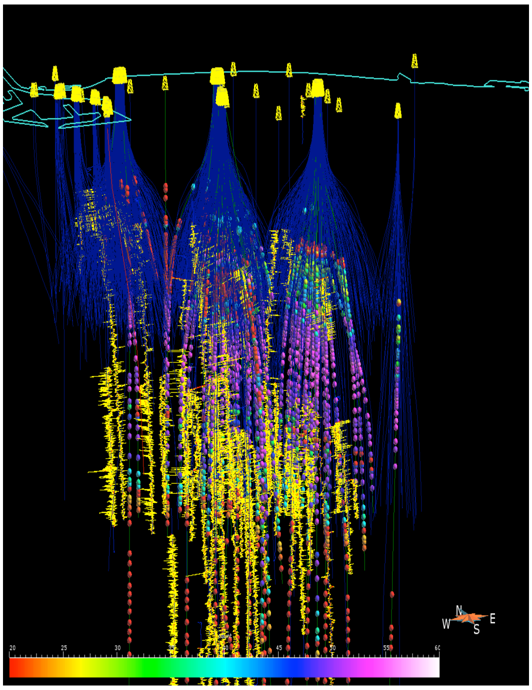

Figure 1: Perspective view of well log database in an oilfield in the southwestern LA basin that was used in our analysis. There are 70 well paths in an area of 7km x 2.5km with more than 400,000 samples of interval travel times by logging tools (converted to Vp); logs in yellow and stratigraphic tops as spheres; 3:1 vertical exaggeration.

Velocity Analysis

Our first analysis compared the velocity values represented in the well logs with the CVMH model values at the well locations throughout the Los Angeles basin and the Wilmington oil field. Given that smoothed (25 m sample) versions of these data were used to develop the velocity model, this analysis simply defined the scale of variability present in the data but not represented in the models. Our analysis shows a standard variation of 6.5% (6.9% in the oil field) around a mean of 0% for the ratio between compressional wave slowness in logs and model.

After removing longer scale trends by normalizing against the velocity model, we then analyzed the well data to quantify the length scales of the vertical and horizontal variability in the velocity structure that they sample. Vertical analyses were conducted in individual wells, whereas the closely spaced well data from the oil field were used to analyze horizontal variability. In the vertical analysis variances were computed for all lags (spacing between pairs of data) between 5 m and 500 m and plotted in a variogram. The smallest lag where variance starts to level out to a background level can be considered the largest correlation distance. Our results show a maximum vertical correlation distance of about 80m at which variance levels reach about 0.004.

In the horizontal analysis, variograms were constructed with lags varying from 20 m to 6 km. The data set was divided into thin (25-m) horizontal layers, in which wells are paired in directions along and across the strike of the anticline. The resulting variances for each lag in each layer are combined in a variogram. The across strike variogram did not show a monotonous trend to higher variances with increasing distance, presumably due to significant bed dips. The variogram measured along strike, however, showed a systematic increase of variances with distance. At a horizontal distance of 500 m the variance reaches background level. We then constructed a similar variogram by pairing of measurements along stratigraphic layers. Following stratigraphic layers increases horizontal correlation distances within the variogram, suggesting a correlation distance of up to

2 km. Using this value, the ratio of horizontal to vertical correlation lengths is about 2000/80 or 25:1.

We also characterized the distribution of the logarithmic variation away from the velocity model for data despiked at 10-ft filter half-width for the LA basin and the oil field data set. Both distributions show good symmetry around a mean close to 0 and a variance of 0.004. Notably, we see that the distribution of velocity variability is distinctly non-Gaussian. In fact, the kurtosis (peakedness) of the sample histograms averages about 12.4 for the LA basin, but it can reach values of up to 50 in individual wells. Since the non-Gaussian shape of the distribution appears to be a robust feature, we plotted the distribution on a logarithmic histogram (using logarithmic frequencies) (Fig. 2). There is a fairly linear drop-off from the mean to both sides indicating distribution of velocity variability that is closer to a power law than a Gaussian. Second-order, but potentially important, features include a small upward curvature on the log-log plot, indicating a fatter-tailed distribution than a simple power law, and an asymmetry in this curvature about the mean value. The latter feature may be a manifestation of high-velocity sand layers intercalated within these shale-dominated sequences. We suggest that a complete stochastic representation of fine-scale velocity structure must represent these features.

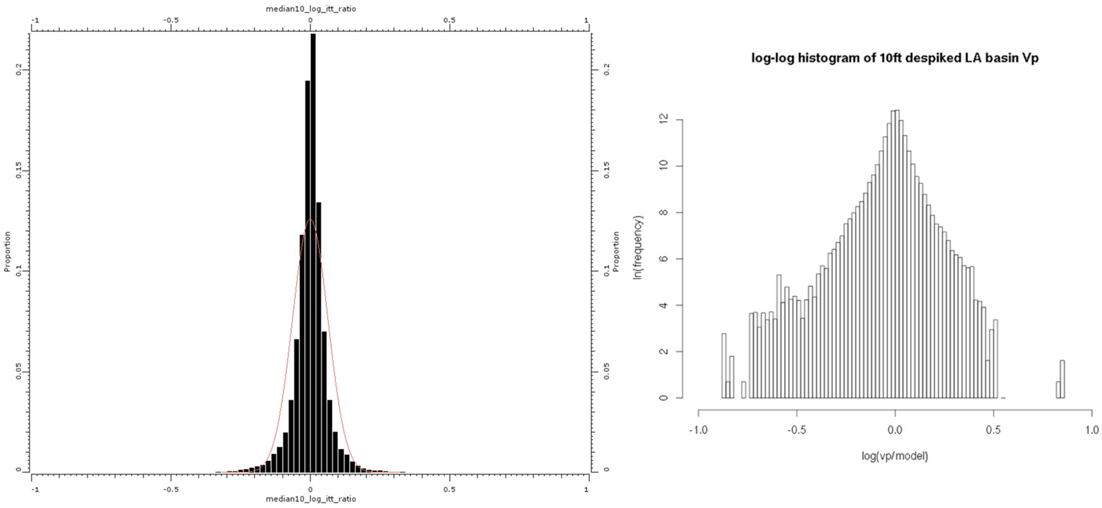

Figure 2: (left) logarithmic histogram of despiked itt relative to the long length scale (400 ft) trend similar to CVMH. (right) Log-log histogram of the same despiked itt.

Publications

Shaw, John H., Andreas Plesch, Thomas H. Jordan, and Xin Song, 2013, Stochastic Descriptions of Basin Velocity Structure from Analyses of Sonic Logs and the SCEC Community Velocity Model (CVM-H), SCEC Annual Meeting, Palm Springs, CA.

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