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Improving 3D Velocity Models and Catalogs: Reliability of Hypocenters and 3D Vp and Vp/Vs Models

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Summary
As our contribution to the SCEC Community Velocity Model (CVM-H), we have added basin velocities to the two tomographic models of Hauksson (2000) and Lin et al., (2007). The Harvard group provided P-wave velocity values at nodes that are located within the basins. In turn, we redetermined the tomographic model and kept the velocities at the basin nodes fixed. As a last step, the final tomographic model (the modified Hauksson (2000) model) was provided to the Harvard group to include in the final SCEC CVM-H 5.3 model (Plesch et al., 2007). In a follwup study, we plan to use these new models to determine the standard error in tomographic models for southern California.

Introduction
Two 3-D crustal velocity models of southern California have been determined from local earthquake data (Hauksson, 2000; Lin et al., 2007). Both models use the same inversion code (SIMULPS from Thurber, 1993) and travel time picks from the Southern California Seismic Network. However, the methodology differs in detail because different starting models, iteration approach, and data selection were used. The Hauksson (2000) starting model was similar to the standard southern California 1D layered model with a near-surface low velocity later, while the Lin et al. (2007) starting 1D model is a continuous gradient model. The Hauksson (2000) starting model also took into account the changes in depth to Moho across the region. The Hauksson (2000) model used a coarse grid inversion first, followed by an interpolation to a more detailed grid and repeat of the inversion. The Lin et al. (2007) model used only the detailed grid but uses more of the travel time data by forming composite events. In this study, we have added the velocity structure of the basins (determined independently by Plesch et al., 2007) to these models and repeated the inversions using the travel-time data set from Hauksson (2000). We compare the 1D profiles of these models as well as reduction in weighted root-mean-square (rms), and the reduction in norm of the model and data. The 3D patterns in these models are similar where the models are well resolved. They differ significantly along the edges, where the model resolution is poor. By adding three new iterations, with and without the near surface basins, we obtain four additional models. We have used all six models to determine a preliminary independent standard error estimate, which is usually underestimated in damped least squares inversions.

The 3D Models
We show four depth panels of the Hauksson (2000) model in Figure 1A. We also show the re-iterated Hauksson (2000) model with basins from Shaw and Plesch in Figure 1B. The basins are more pronounced when they are included in the starting model, while the deeper parts of the models exhibit slightly higher velocities. The top layer at 1 km depth (below sea level) shows low velocities within both the onshore and offshore basins.

We show four depth panels of the Lin et al. (2007) model in Figure 2A. We also show the re-iterated

Lin et al. (2007) model with basins from Plesch et al (2007) in Figure 2B. The Lin et al model behaves similarly, when the basins are added, with better defined basins and only minor increases in Vp at greater depths. The top layer at 0 km depth (sea level) does not include the offshore basins that are below sea level.

Comparing Model Properties

In Figures 3 and 4 we show how the Vp and Vp/Vs models change as a function of depth. The two models exhibit different behavior as a function of depth suggesting that they are capturing different amounts of variations in Vp and Vp/Vs with depth. The Hauksson model exhibits more gradual gradient with depth and shows a strong scatter of points with distance. The Lin et al. model exhibits a very rapid gradient to a Vp between 6.0 to 6.6 km/s but shows a smaller scatter in velocity values within each layer. The Vp/Vs starting models are different, with the Hauksson model using 1.73 while the Lin et al. model used 1.78.

In Figure 5a and 5b we show the average effects of adding the basins to the two models. When the basins are added, the Vp of the top layers decreases and the Vp-values at grid nodes of the bottom layers increase by several percent. The net effect of adding the basins thus should not systematically change the depths of the earthquakes.

In Figure 5c, we show the data variance for the two 3D velocity models versus model length. The model length increases as the data variance decreases or is absorbed into an increasingly complex model. The Lin et al model has a somewhat larger model length in part because in this case we are not using the original data set of composite events to re-iterate the model.

Earthquake Relocations

In Figure 6a and 6b, we show depth histograms for the events used in the inversions for the two basin modified models from Hauksson (2000), and Lin et al (2007). Both histograms look similar, and show higher seismic activity at depth near the brittle ductile transition. These observations suggest that the focal depths are not strongly dependent on the specific 3D model. However, a 1D model would provide a different and probably more scattered depth distribution.

In Figure 6c and d, we show histograms of the root-mean-square (RMS) residuals of the earthquake locations for the two 3D velocity models. The two histograms are very similar and thus demonstrate that both models do a similarly good job of relocating the earthquakes and explaining the station residuals.

Preliminary Evaluation of Standard Error

Two travel-time based tomographic models are available for southern California, Hauksson (2000) and Lin et al. (2007). We have done a preliminary study to use these models and associated 'basin added' models to determine standard errors. Usually, the standard errors are determined by using the covariance matrix to provide the mapping from data error into model error. However, this approach is known to underestimate the standard error easily by a factor of 2 and in some cases by a factor of 5. Using the six models, we calculate mean velocity and corresponding standard error at each grid node in the model.

The preliminary results of this study show that the standard errors are high where the models are poorly constrained. The near-surface layers of 0 or 1 km depth have one sigma errors of 0.4 km/s or larger. The layers at 3 or 4 km depth show large errors only in the basins. Under the very deep Ventura basin, the basin related standard errors extend to depths of 10 km. This also reflects the fact that the basins had to be added as a priori information and were not recovered during the inversion.

Similarly, the standard errors are high in the Salton Trough region. This is in part caused by lack of constraints on the focal depths. Other regions of high standard errors in the depth range of ~6 to ~20 km are mostly along the north and west edges of the model. We speculate that uncertainties in focal depths along the edges lead to higher standard errors in the 3D velocity models. The standard errors are also high in limited regions scattered through out the model where ray coverage may be sparse.

We conclude that the 3D models have low standard errors once we move inland from the coast. For example the 3D model is well resolved across the San Andreas and San Jacinto faults.

Conclusions

The comparison of the six different velocity models illustrates the complexity of the 3D crustal velocity structure in southern California. The deep basins, large topographic variations in depth to Moho, and uneven distribution of sources and receivers affect the resolution of the 3D models in many different ways.

The near-surface basins are not well resolved by the tomographic method. Once the basins are included in the starting model, the average velocity depth function changes because the lower crustal velocities become higher. Comparison of the two models also suggests that it is appropriate to add a Moho surface, especially because the Moho ranges in depth from 22 km to 46 km; from the Continental Borderland to the high Sierras. Only the models based on Hauksson (2000) include a Moho.

The uneven distribution of sources and receivers leads to scattered distribution of low and high standard errors. An unexpected region of high standard errors is revealed along the western Peninsular Ranges, and to the north in central California, which have sparse station distribution and poor depth control.

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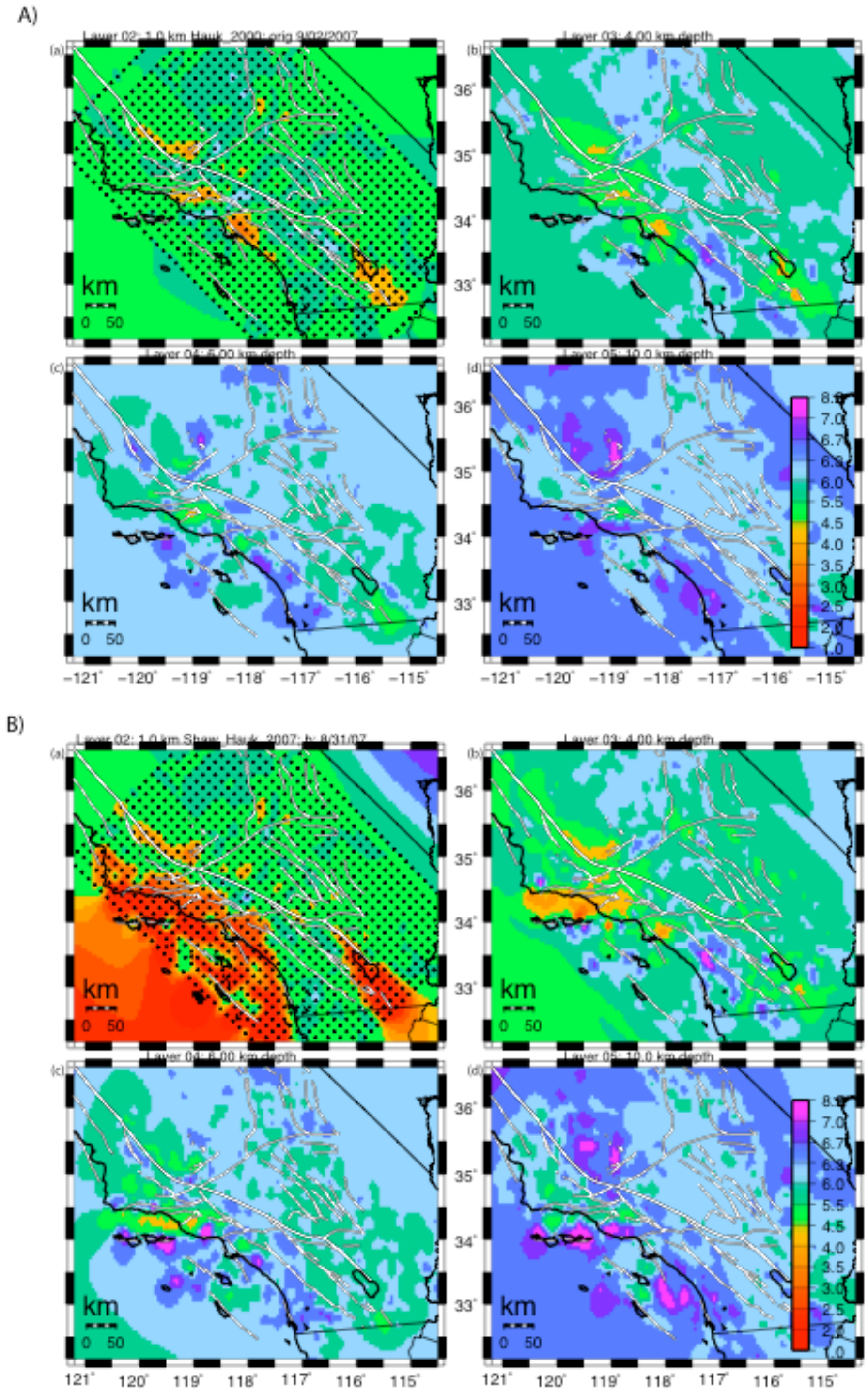

Figure 1. Horizontal slices of Vp models at 1, 4, 6, and 10 km depth. (A) The original Hauksson (2000) Model. (B) The Hauksson (2000) with Shaw/Plesch Basins

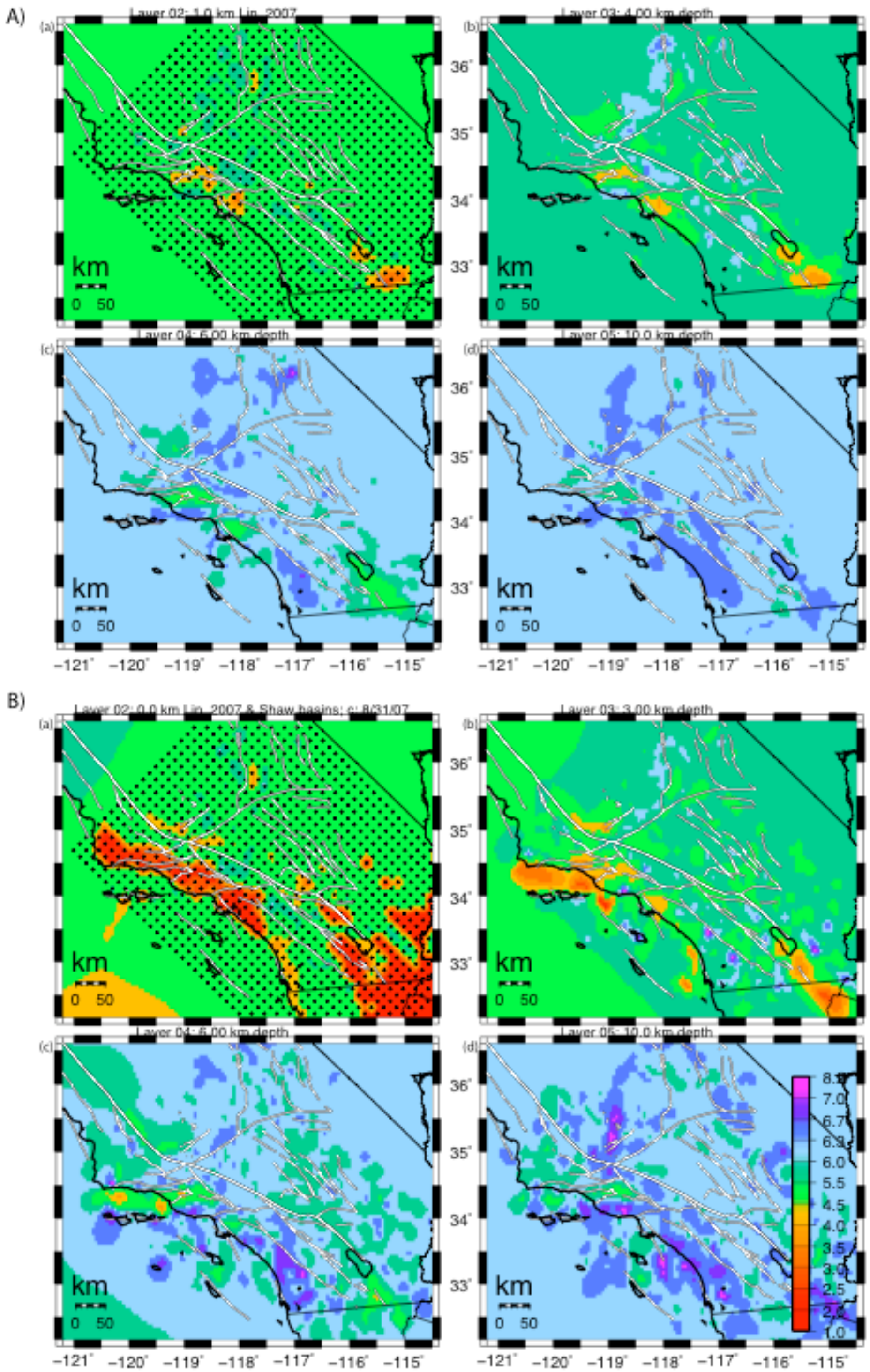

Figure 2. Horizontal slices of Vp models at 0, 3, 6, and 10 km depth. (A) The original Lin et al. (2007) Model. (B) The Lin et al. (2007) with Shaw/Plesch Basins

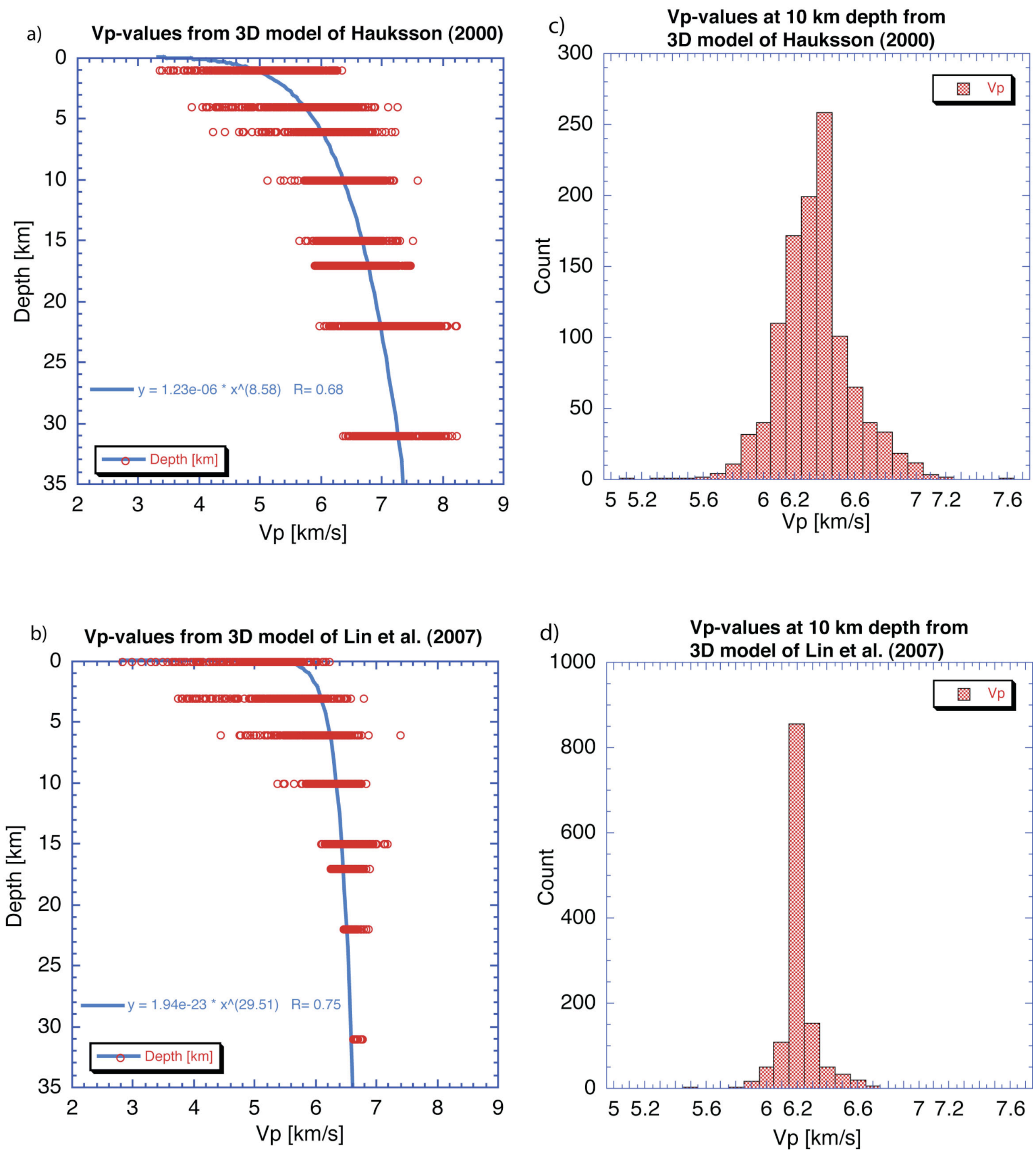

Figure 3. Depth profiles and distribution of velocities at 10 km for the Vp models of Hauksson (2000) and Lin et al. (2007).

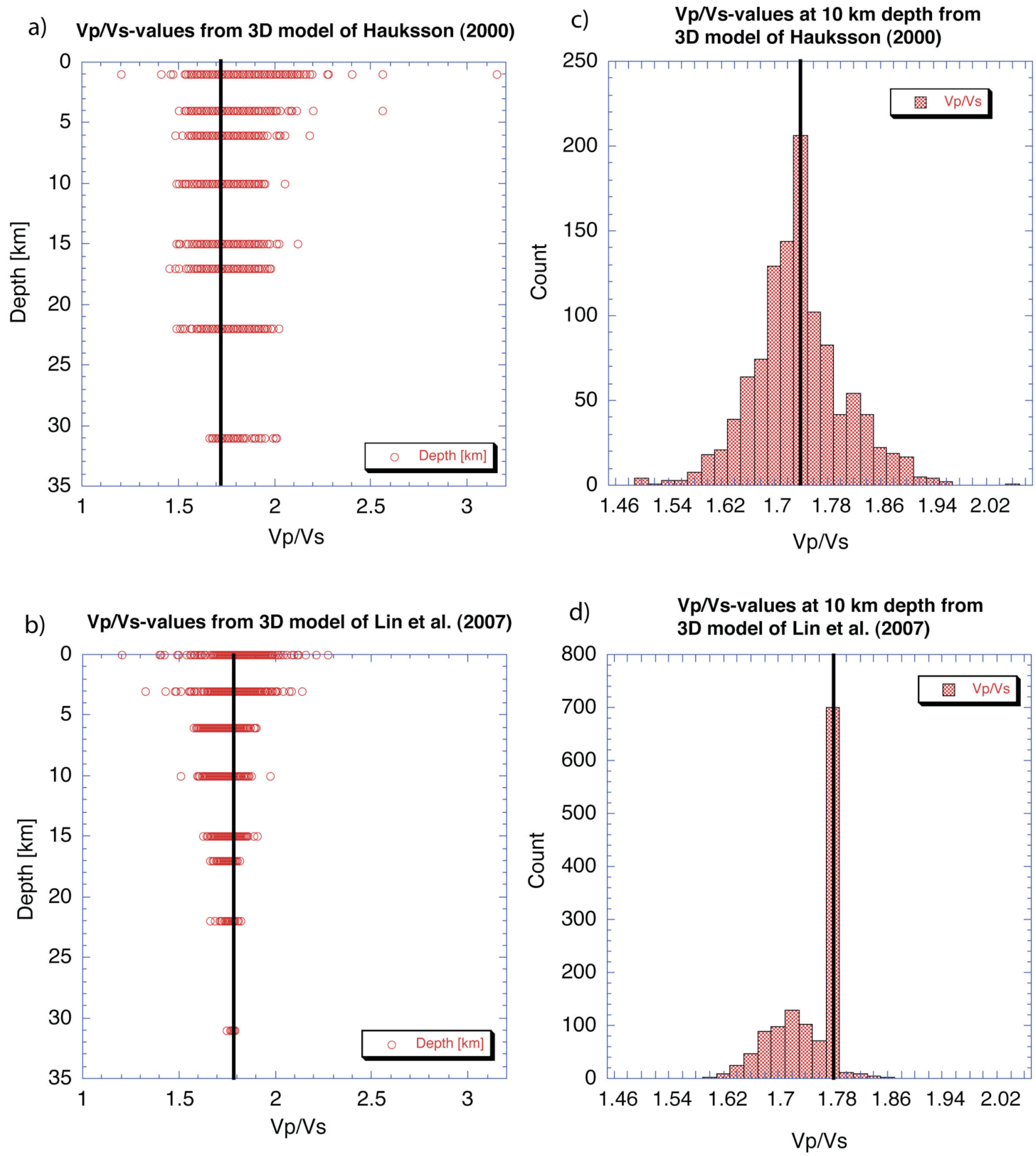

Figure 4. Depth profiles and distribution of velocities at 10 km for the Vp/Vs models of Hauksson (2000) and Lin et al. (2007). The vertical (black) line is the starting Vp/Vs model of 1.73 and 1.78.

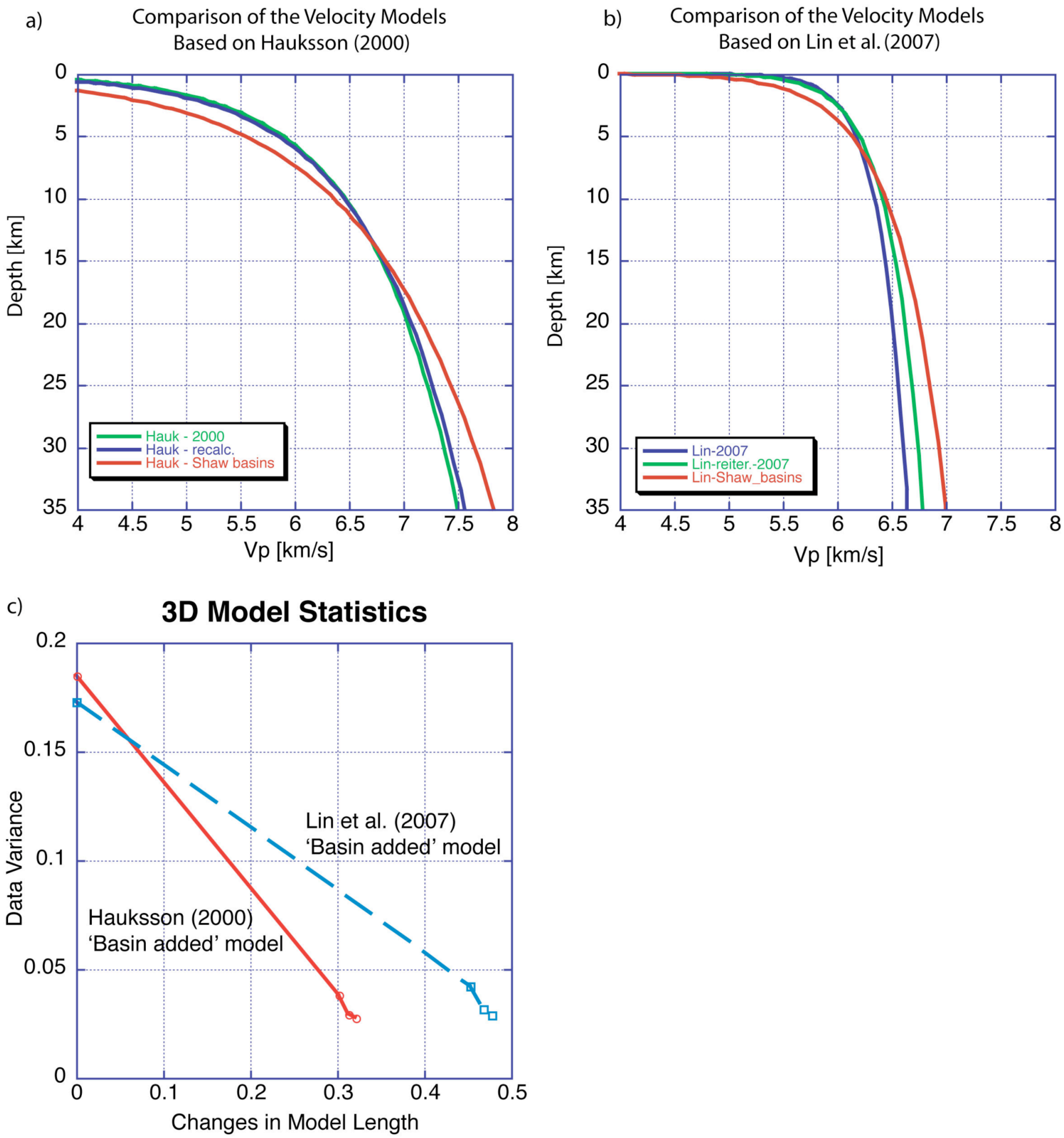

Figure 5. (a) and (b) Comparison of the Hauksson (2000) and Lin et al. (2007) velocity models with and without basins. (c) Changes in data variance as a function of model length for the 'basin added' models.

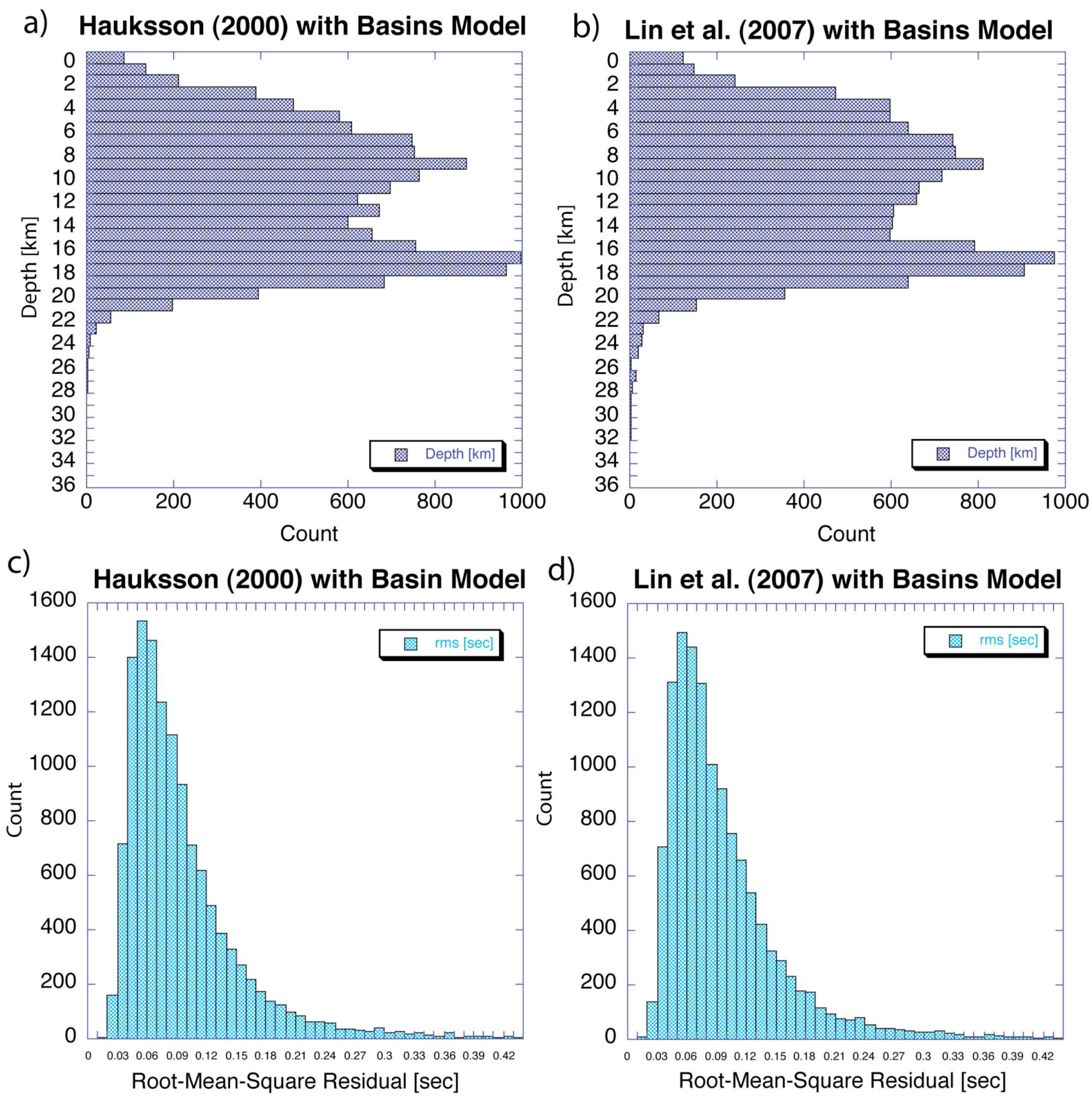

Figure 6. (a) and (b). Depth distribution of the earthquakes used to re-iterate the Hauksson (2000) and the Lin et al. (2007) models, and relocated with the respective model. (c) and (d) Root-mean-square residuals of travel times for the same relocated earthquakes using the Hauksson (2000) and Lin et al. (2007) 3D models.