SnT 2019
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

A new approach for calculating 1D local velocity model using Particle Swarm Optimization technique

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1 Introduction

A new method for calculating 1D local seismic velocity model is proposed by using one of the powerful methods in global optimization techniques named Fuzzy Self-Tuning Particle Swarm Optimization (FST-PSO). It generates random particles (velocity models) in a pre-defined solution space in which after number of iterations they lead to a model that yields best fits to the data. Not using the partial derivatives of travel-times respect to model parameters and performing no matrix inversion, it enables to speed up the calculations. In addition, because the PSO family members use only random processes to generate new models, they are inherently stable and avoid all numerical problems encountered in deterministic methods. Taking advantage of fuzzy logics implemented, no parameters are needed to be adjusted including social, cognitive and inertia for running the program. The proposed methodology is very easy-to-use, effective and powerful. Its proficiency was checked on both synthetic and real datasets. This method was applied to calculated 1D velocity model of the Southern-part of central Alborz Iran, which its velocity model has already been calculated. The comparison between these two models shows a good correlation between them, while the reductions of RMS and hypocentral errors using the FST-PSO-model are obvious.

2 Method and Synthetic

We utilized FST-PSO, a modified and an improved version of the FL-based PSO developed by Nobile et al., (2018). In this approach the velocity and position of every particle are updated according to individual particle settings: inertia, social and cognitive factors, each one related with a fuzzy variable. These values are independent from the values of the other particles in the swarm. To dynamically determine the values of the *i*th particle settings during iteration *t*, FST-PSO makes use of a fuzzy rule-based system (FRBS) which is included of 15 fuzzy rules (Nobile et al., 2018). These rules are defined by two main concepts: the relative distance between the particle and the global best ***g***, and a function by which the fitness improvement of each particle with respect to the previous iteration is measured. Using FST-PSO all settings are automatically updated after each iteration and the performance and accuracy of the final outputs are considerably improved (Nobile et al., 2018). The criterion we proposed here, consist of three steps:

1- Boundary determination for solution space: In many real cases we have insufficient geological and geophysical information regarding the velocity structure of the study area. One approach would be to use travel time curves and estimate the average velocity variation beneath the crust as a rough model.

2- Velocity model calculation: The program starts to generate N random velocity models, and passes all of them to the objective function defined in FST-PSO. The objective function evaluates the mean RMS and returns this value as a measure of goodness of fit for each model. The output of this step is a model which the minimum value of mean RMS is obtained by. The program would continue and update all admissible models until whether a pre-defined mean RMS is obtained or maximum number of iteration reach.

3- Error assessment: As the heuristic methods such as FST-PSO cannot provide confidence interval itself, one way to obviate this deficiency is calculating the mean and standard deviation after performing multiple individual runs of the program. Regarding this, the approach consists of establishing a minimum–maximum range for each parameter, taking into account the geophysical models that have been sampled within the X% nonlinear uncertainty region.

To show the reliability and efficiency of the FST-PSO algorithm for evaluating 1-D velocity model using local earthquake travel times, a synthetic test is performed. We used couple of python codes for generating synthetic earthquakes, estimating rough velocity model by plotting travel time curves, and running FST-PSO in which tuned for Hypoellipse program (Lahr, 1999) as the objective function. In the first step, 144 synthetic earthquakes were generated using a pre-defined 1-D velocity model called "true model", distributed over a rectangular fault plane. In majority of real cases we may have insufficient geological information about the region under study especially regarding the velocity structure. In such a case, one way is to estimate a rough velocity model using travel time curves.

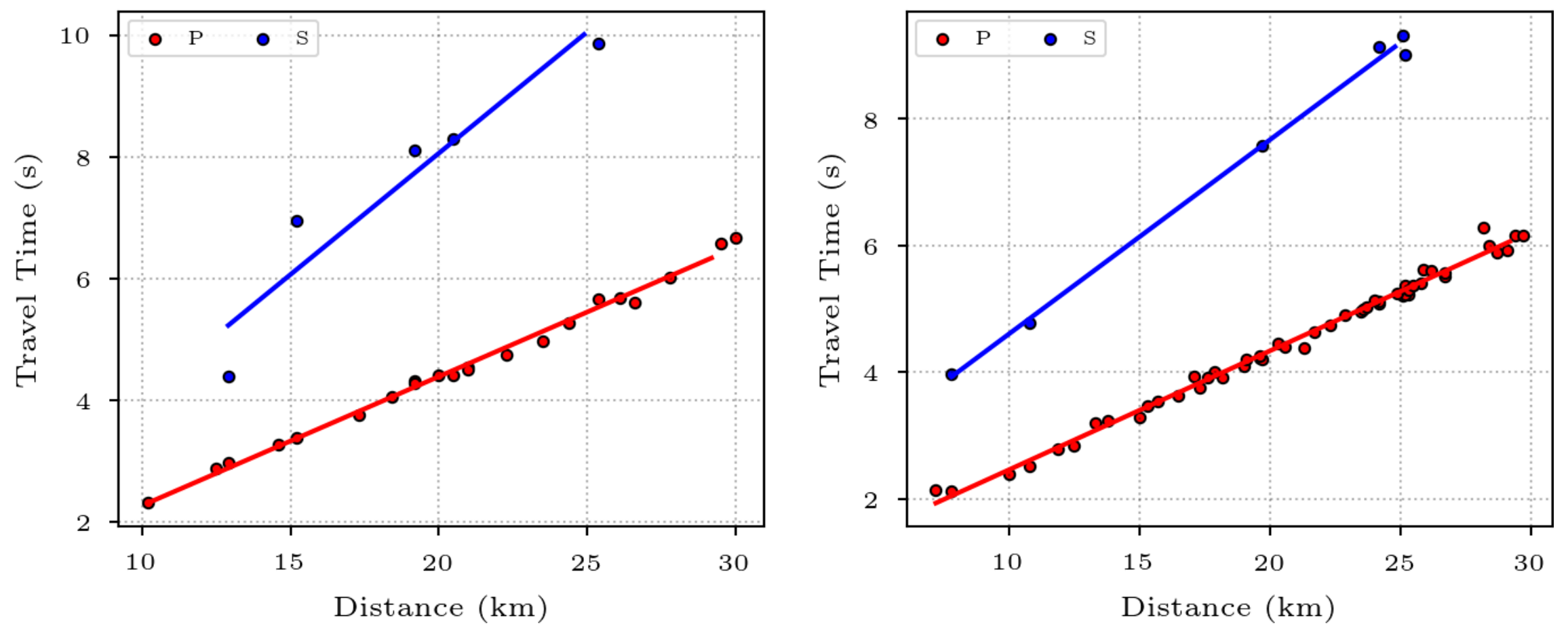

Fig. 1, Travel time curves of P and S phases generated from synthetic earthquakes. Left and right, earthquakes for depth range 0-4 and 4-8 respectively, all recorded by stations in range 0-30 km.

Regarding our synthetic case, we are going to find a 4 or 5 layer velocity model. So the first layer can be defined from 0-4 km, the second one 4-8 km, the third one 8-12 km, the forth one 12-16 km and the last one from 16-20 km. Then the synthetic earthquakes are selected based on calculated depths and group them in relevant layers to plot travel time curves in different distance range (Fig. 1). We consider 5% and 15% errors to define a solution space for velocity and thickness of each layer respectively needed by FST-PSO to calculate velocity model. After defining the solution space, applied the FST-PSO and run the program 10 times for estimating a reliable error bounds. The output of the first run is shown in Fig. 2.

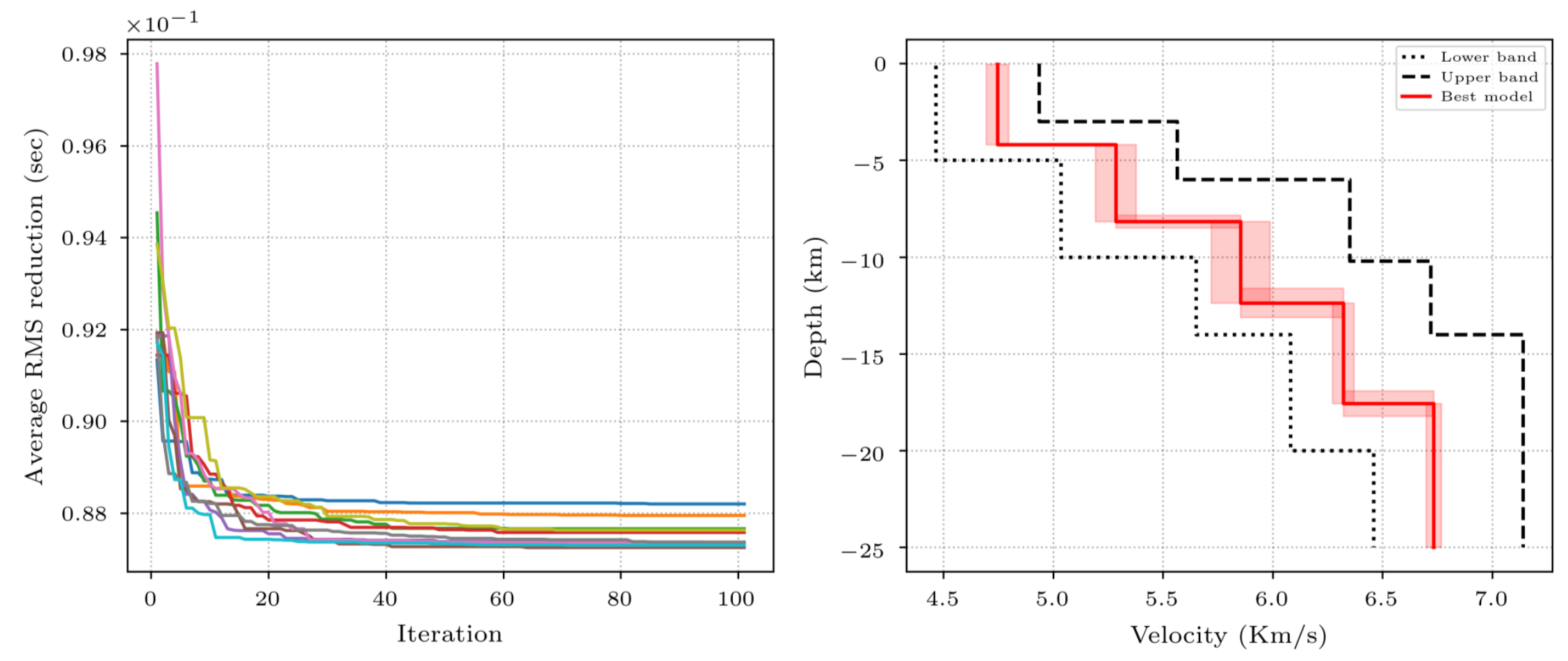

Fig. 2, The RMS reduction per new model in 100 iterations for 10 independent runs (colored lines).

3 Application to Central Alborz, Iran

We applied our new method on a unique data-set of local earthquakes to calculated 1-D velocity model of the SW of central Alborz, Iran. The total number of 122 local earthquake were used for calculating the 1D velocity model for this region. Raypaths coverage and the final velocity model calculated by FST-PSO are shown in Fig.3. The P-wave velocity of each layer in FST-PSO-model is consistent with those of Abbasi-2010 model.

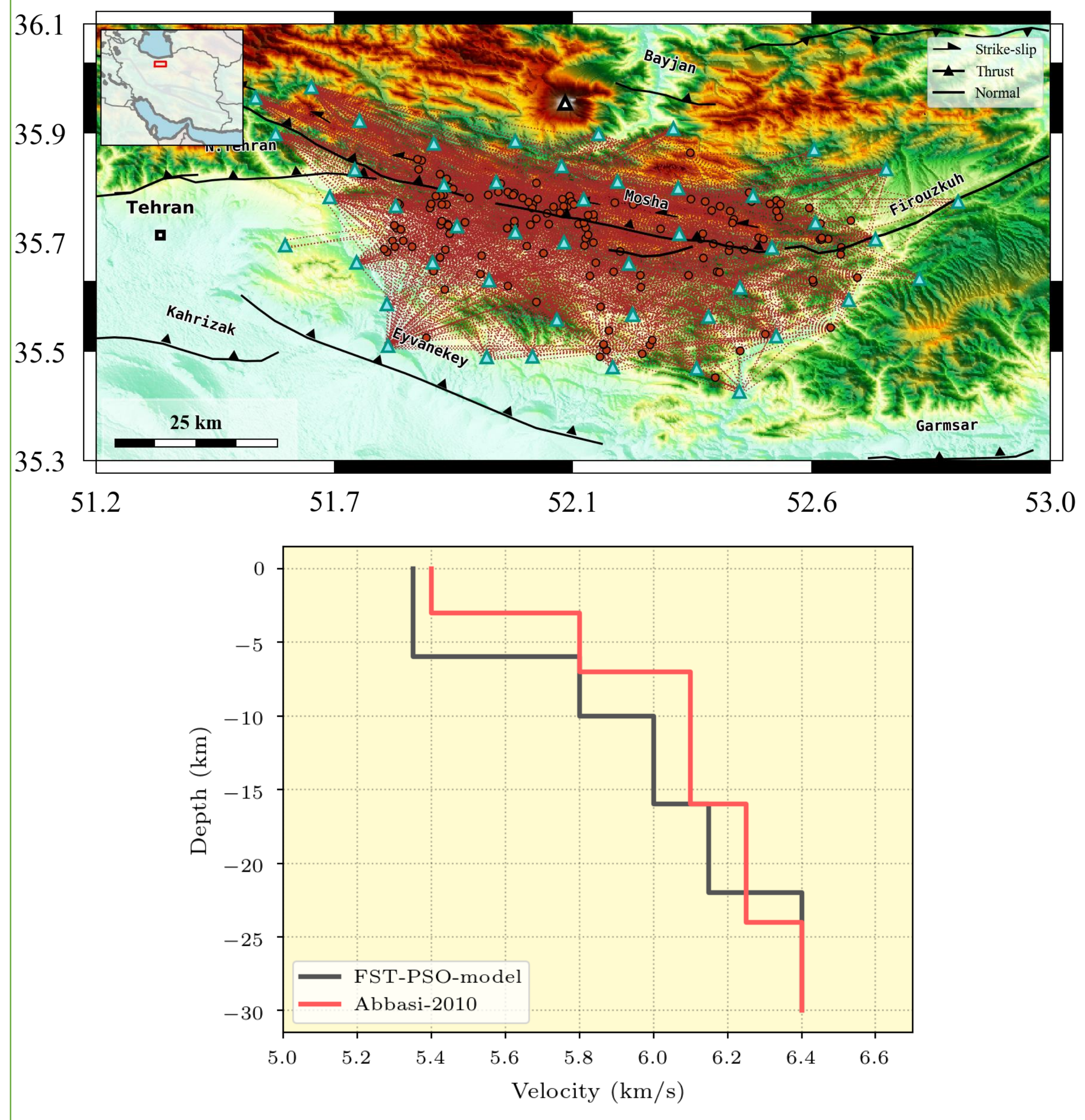

Fig. 3, Region of study area with raypaths coverage (top) the comparison of calculated velocity model between FST-PSO model and Abbasi et.al, 2010 (bottom).

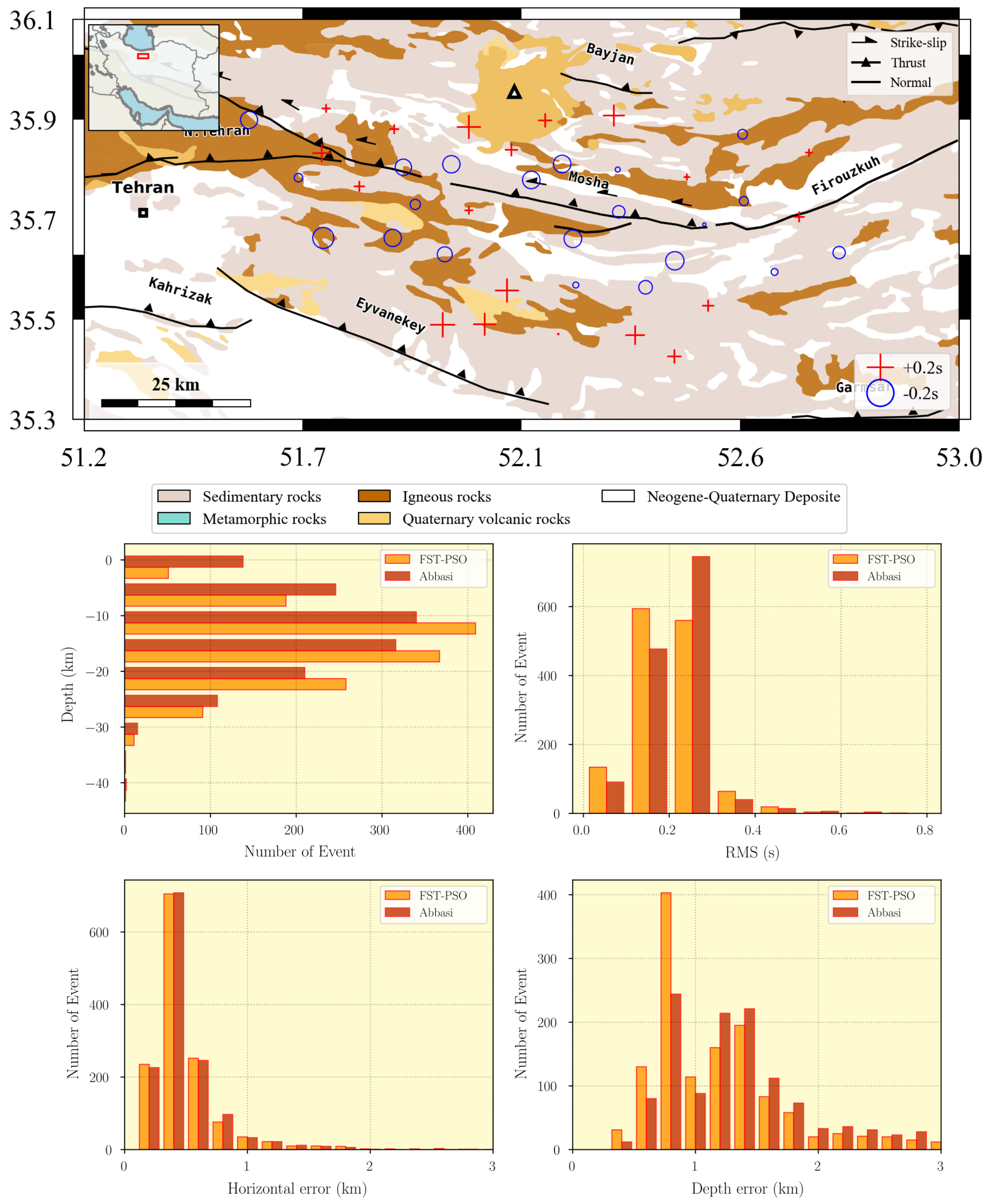

Fig. 4, Station correction map overlying geological map (top) Statistical results between two velocity models regarding focal depth, RMS, horizontal and depth errors (bottom).

4 Conclusion

Relocation of events using our new velocity model and station corrections results to considerable reduction in RMS, horizontal and depth errors which obviously lead to a more precise events catalog (Fig. 4). The spatial distribution of station corrections correlates well geological features (Fig. 4). The positive delays in this area are consistent with Pliocene to Quaternary sedimentary cover spread in different parts of the study area, while the negative delays indicating on high velocity anomaly beneath the station are observed on hard Igneous rocks mainly around the Mosha fault. Positive delays of few stations located on hard bed rocks can be related to the shallow magma chamber of the Damavand volcano.

5 References

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