1-D VELOCITY MODEL FOR SYRIA FROM LOCAL EARTHQUAKE DATA

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ABSTRACT

We performed inversion to estimate a 1-D velocity model of the crust and uppermost mantle under Syria with station corrections following the procedure proposed by Kissling et al. (1994), where simultaneous inversion for structure and hypocenters was carried out, using data of 542 selected events from the Syrian National Seismological Network during 1995-2004. we determined both P-wave velocity (Vp) and S-wave velocity (Vs) models. In addition to the optimal 1-D velocity model the inversion provided a set of station corrections. Using this new model we relocated the 542 selected events. The comparison between the previous solutions and the new solutions shows improvements of the total RMS values, which suggests that it is possible to improve the accuracy of hypocenter determination by this new model.

Keywords: 1-D velocity model, Station correction, hypocenter determination

INTRODUCTION

The Syrian National Seismological Network has been in operation since 1995. It started with 20 seismic stations (short period 1 Hz). This set of stations was deployed in the western part of the country along the Dead Sea Fault System, which is considered the most active region in the north part of the Arabian Plate. Later in 2003, more 7 Stations (short period 1 Hz) deployed in the north-eastern part of the country to monitor the seismic activity in the Euphrates graben and Abd-el Aziz Sinjar uplift (Figure 1). The local network recorded about 2762 seismic events form 1995 to 2004. These events were located by SEISAN program (Haviskov et al., 2005). The velocity model used by SEISAN for hypocenter determination was assembled from refraction, reflection, well logging and gravity data, but not according to seismic data generated from natural seismic sources. The appropriate velocity model is necessary for a variety of purposes, including the correct hypocenter determination, 3-D tomography, moment tensor inversion and so on. Lack of such 1-D velocity model for Syria was the main inspiration for this research. The described 1-D velocity model will be able to be used for routine and more detailed

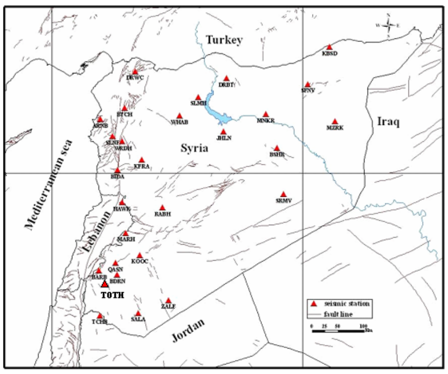

Figure 1.The distribution of the local network.

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seismic data analysis for Syria. Syria is located in the north-western part of the Middle East which is tectonically and seismically active.

The major tectonic settings in and around the country are the Anatolian-Iranian plateau and Zagaros mountains, the Dead Sea fault system, the intracontinental Palmyrides fold-thrust belt, and Abd Alaziz-Sinjar uplift.

Syria has been monitored locally for 10 years by 27 permanent digital seismic stations. About 2762 events have been recorded by the local network since 1995 till 2004. Most of recorded earthquakes are micro-earthquakes (Mc<3.0) while the largest local recorded earthquakes was on December 24, 1996 in Palmyrides belt zone with a magnitude 5.4 (Mc). Most of the events concentrated on the margins of the Arabian plate (Dead Sea fault system, East Anatolian fault System) and on the intracontinental Palmyrides belt zone, besides some of the events from the oceanic crust of Mediterranean sea and fewer events of the continental collision zone of Zagros (Figure 2).

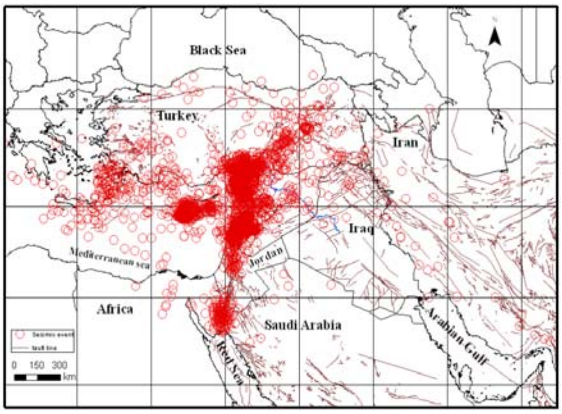

Figure 2. The recorded earthquakes by the local network from 1995-2004.

DATA AND A PRIORI VELOCITY MODEL

The hypocenter determination of the raw data was done by SEISAN program. P and S arrivals were picked manually according to the quality of their onsets. P-wave arrivals have clear onsets since they are the first arrivals but S-waves have less quality than P-waves since it is difficult sometimes to distinguish clear onsets. For the inversion process, the well located earthquakes were selected with a good distribution along the active regions inside and surrounding the country. Out of 2,762 recorded earthquakes by the Syrian National Seismological Network, a first data set resulted in 588 events with 6 (P and S) arrivals and more. Forty six events from the first set were rejected and the rest 542 events are shown in Figure 3.

The definition of a priori velocity model is an initial reference model and a reference station. We established the initial reference model according to the pervious geological and geophysical studies in Syria and Jordan. The reference station used for the inversion is (WRDH) station (see figure 1). It is situated to north-west of the local network. The station is located on good and hard limestone rocks belong to Cretaceous period. It has the largest number of P-wave and S-wave observations. The total P-waves and S- waves recorded by this station are 682, P-wave arrivals are 477 and S-wave arrivals are 235, respectively.

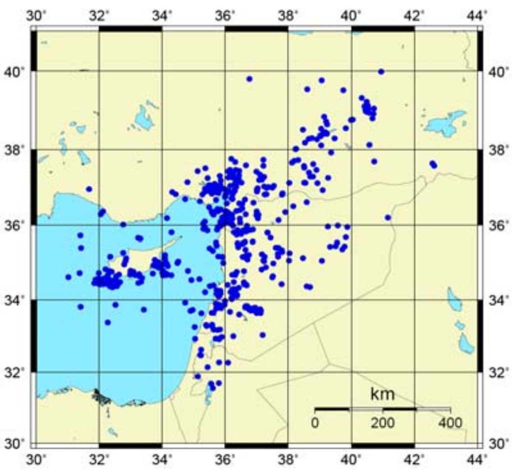

Figure 3. the selected events for the inversion process.

VELOCITY MODEL ESTIMATION

Initial inversion run was done for the 542 selected events by using the initial reference model which I mentioned to in the previous section. To improve the reference model many trials were achieved. First we chose a velocity model consisting of 19 layers; each layer has a thickness of 2 km up to 36 km depth. The aim of this fine model is distinguishing the smooth change from the sharp change in the velocity with depth. Another inversion was made on this model. The resulting model showed a clear changing velocity on 4km for both P-waves and S-waves. On 10 km just P-waves velocity increased but not S-waves velocity. Following down the velocity clearly increased on 18 km depth and 34km depth for P and S wave-velocities. The trial resulted of a new initial reference model after combining the closing layers has the same velocity. This model consists of five layers for Vp and four layers for Vs. This improved model was used again for inversion which produced the final velocity model.

RESULTS

The resulting velocity model shows increasing P-waves and S-waves velocities with depth as follows. The sedimentary layers up to 4 km depth have P-wave velocity of 5.68 km/sec and S-wave velocity of 2.99 km/sec (Vp/Vs = 1.89). From 4 km to 10 km depth P-wave velocity increased up to 5.87 km/sec and Vp/Vs=1.69, from 10 km to 18 km depth P-wave increased again to 6.18 km/sec, S-wave velocity does not change from 4 km to 18 km and has a value of 3.48 km/sec and Vp/Vs=1.78. Both velocities increase again at 18 km/depth. P-wave velocity is 6.74 km/sec while S-wave velocity is 3.95 km/sec and Vp/Vs=1.70. Pn has a value of 8.0 km/sec, Sn has a value of 4.64 km/sec and Vp/Vs=1.72 (Figure 4). To check the best Moho depth which is more suitable for the final model. We fixed the velocity. Then we applied inversion runs by changing Moho depth. We changed the Moho depth from 30km to 42 km depth by 1km step. Since the best value was ranging between 37 km depth and 38 km depth we did one more inversion for 37.5 km depth. We have obtained the best Moho depth on 37.5 km with respect to less RMS value. Fixing the velocity model during the inversion also allow the station corrections and the hypocenters approach a local minimum. S-wave time correction for the reference station has a value approaching zero on 37.5 km depth.

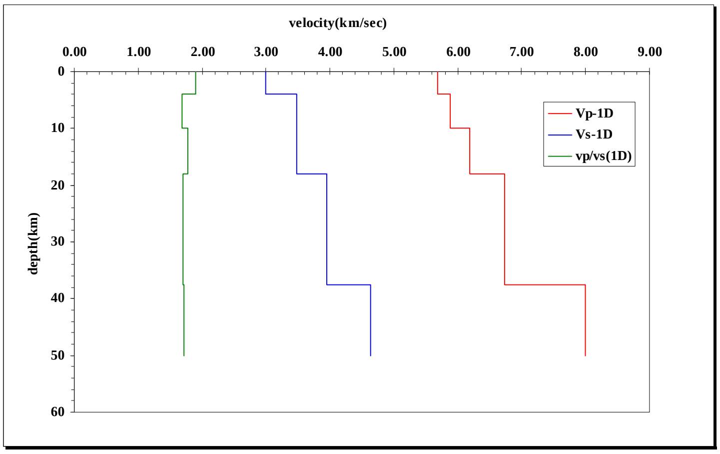

Figure 4. The final 1-D velocity model and the Vp/Vs ratios for the both models.

In addition to the velocity model the inversion procedure used here provides two sets of station corrections. One for P-wave time station corrections and the other one for S-wave time station corrections. These corrections were done according to the reference station. Only the P-wave station correction fixed for the reference station (set =0), and the S-wave correction is free floating. Station corrections can reduce the effect of the lateral inhomogeneity for the velocity model. There is no correlation between the station correction and the station elevation, because we considered the station elevation for the inversion. The obtained station corrections just include the effects of the subsurface geology and the Moho depth (Figures 5, 6). The negative time station correction means that the station is located in local high velocity area with respect to the reference station.

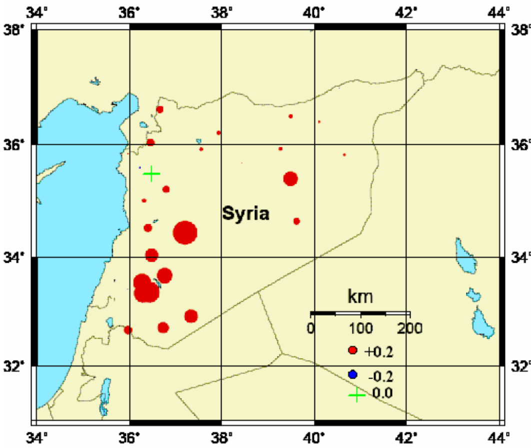

Figure 5. P-wave time station corrections

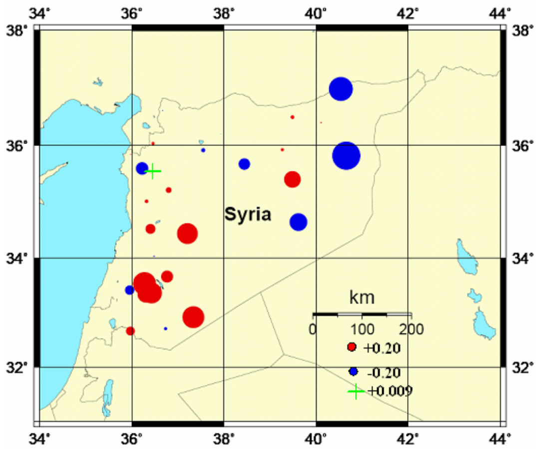

Figure 6. S-wave time station corrections

DISCUSSION

The reference station WRDH has a zero P-wave time station correction and S-wave time station correction has an almost zero value (+0.009). Stations KFRA, BIDA, BTCH, DRWC, HAWK, MNKR, DRBT, and SFNV have small positive values of P and S-wave time station correction. It may attributed to the surface geology. Since all these stations are located on a less suitable geological conditions with respect to the reference station. Stations SLNF, BARB have both negative P and S-wave time station corrections, and the station sites belong to Upper Jurassic and located on massive homogenous limestone rocks. These station sites are better geologically than the reference station site. Station KBSD has both negative P and S-wave time station corrections. The station site is located on basaltic rocks which is harder than reference station site. Station MZRK has a small P-wave time correction, but a negative S-wave time correction. This station is located on basaltic rocks which is harder than the reference station site. Stations RABH, QASN, KOOC, TOTH, BDRN, and BSHR have high positive P and S- wave time station corrections. This is likely to be due to the deeper Moho which we will discuss later. Stations TCHB, ZALF have both positive P and S-wave time station corrections. Station SALA has a positive P-wave time station correction and a small negative S-wave time station correction. Probably the delay time of these stations has been affected by a deeper Moho and these stations have been located in a wide fractured area. Station SRME has a positive P-wave time station correction and a negative S-wave time station correction which is likely to be come from the small number of observations (four P-wave arrivals and three S-wave arrivals). Station WHAB has a small P-wave time station correction and a small S-wave time station correction which are within the ranges of the estimated errors. Station JHLN has a small positive P-wave time station correction and negative S-wave time station correction. The reason of which is not clear.

To get a rough estimate of the Moho depth beneath the Palmyrides region where stations RABH, QASN, KOOC, TOTH, BDRN and BSHR are located. we calculated the average P-wave time station correction for these stations. The average value was 0.59 sec. The difference crustal thickness beneath the Palmyrides with respect to the crustal thickness beneath the reference station is the product of the average P-wave time station correction and the velocity in the lower crust (Vp=6.74km/sec). The estimated value was around 4 km. We added this value to the Moho depth beneath the reference station. The result (41.5 km depth) is the Moho depth beneath the Palmyrides. This value is coincident with the gravity survey along the Palmyrides region where the estimated Moho depth is 38-42 km (Best et al., 1990).

The inversion procedure gave new hypocenter locations for the 542 selected events. To compare this result with the hypocenter location using the current velocity model which is being used for the routine data analysis by the Syrian network. We performed a joint hypocenter determination for the 542 selected events using this model by VELEST in single event mode (Figure 7). The estimated 1-D velocity model showed a reduction of total RMS value of all events compared to the current velocity model (Figure 8). Our interesting part is inside the network, where more precise results are expected. The horizontal hypocentral variations are small especially western part Syria where the network distribution is denser. The depth cross sections under Syria show that the new distributions reduced some space in the data where some events shifted up to the upper crust. The average deviations in origin time, x, y and z were 0.77 sec, 4.2 km, 3.7 km, 3.1 km respectively.

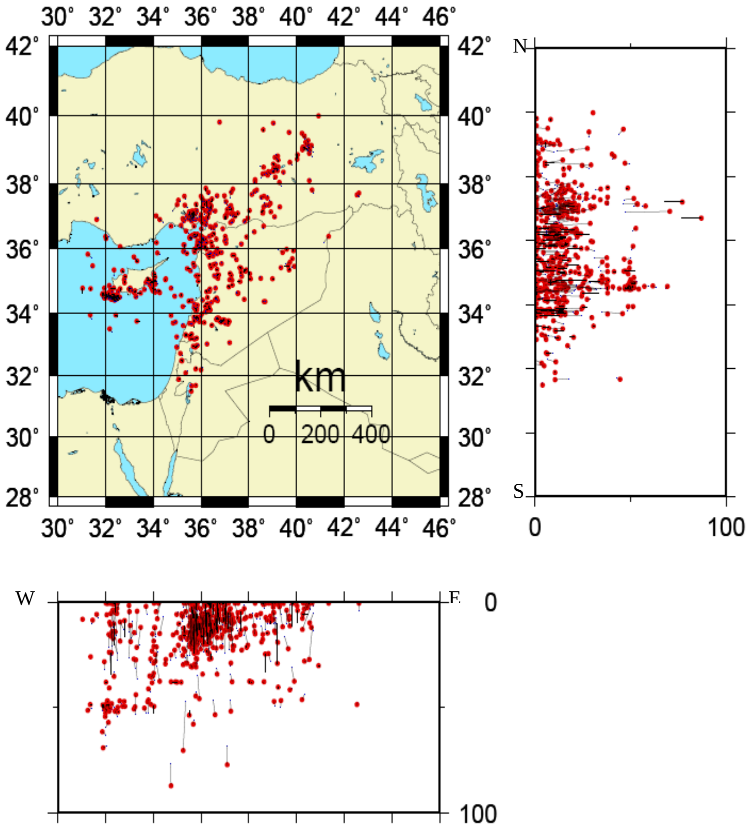

Figure 7. Comparison between the relocated hypocenters by the new velocity model and the hypocenters by the current velocity model.

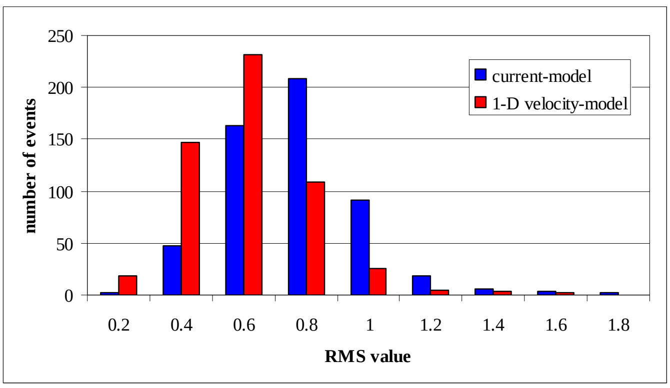

Figure 8. Difference of RMS of the residuals between the hypocenter locations using the current velocity model and the estimated 1-D velocity model

CONCLUSION

The present study used an efficient method for estimating the 1-D velocity model by solving the coupled hypocenter-velocity model problem. We inverted a set of earthquake data by using VELEST program. The program minimized P-wave and S-wave residuals of the data set according to the procedures outlined by Kissling et al., (1994). The inversion resulted of: (1) 1-D velocity model including P and S-wave velocities. (2) Hypocenters have been relocated with higher accuracy. (3) P-wave time station corrections have a good accuracy and coincident to the local geology. (4) S-wave time station corrections may have a less accuracy than P- time station corrections due to lower quality and quantity of data. (5) An appropriate Moho depth has been estimated. (6) Moho depth has a significant effect on station corrections in addition to surface geology. Unfortunately our estimated 1-D velocity model is limited by a few numbers of observations for the north-eastern part of the local network.

We hope that the new model will be useful for smooth routine and detailed seismic analysis for the Syrian National Seismological Network.

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