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Interactive
Comment

Interactive comment on "Studying local earthquakes in the northern Fennoscandian Shield using the data of the POLENET/LAPNET temporary array" *by* O. A. Usoltseva and E. G. Kozlovskaya

O. A. Usoltseva and E. G. Kozlovskaya

kriukova@mail.ru

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We thank Anonymous Referee #1 for critical and constructive comments on our manuscript and useful references. We have performed additional calculations, deleted Table 4, changed the text and other tables. We have redrawn figures 1,2,7,11-17, deleted Figure 8 and added 2 new figures. We have carefully incorporated all the comments and suggestions into the revised manuscript attached below. The revised parts are highlighted by red. We have added 8 new figures and 3 new tables in supplement.

Major comments:

1) The authors should make clear how many earthquakes and blasts/explosions they use in the manuscript and which criteria are used to select these events.

[Reply] In our study we use recordings of 34 local earthquakes for relocation. The main criteria for selecting these events was the amount of arrivals available for relocation and good stations coverage. For local seismic tomography we used more events (36 local earthquakes and 9 local explosions) to provide the even ray coverage.

In section 2 they state that the selected events are recorded by more than 6 stations, but the do not mention how many phases are required (presumably only 7 P phases or more).

[Reply] We have clarified in the text that selected events need to have more than 6 first arrivals of P wave.

In Table 3 there are events with azimuthal gaps of more than 180 degrees which degrades the location accuracy.

[Reply] We recalculated hypocentres with a new data set, in which we added the first arrivals of S waves determined for LAPNET stations and the first arrivals of P wave from permanent stations in Sweden for the period 05.2007- 05.2008 (the data source is the FENCAT catalogue). In a new Table 3 the azimuthal gaps are less than 180 degrees for all events.

In section 4 it is stated that 34 events were relocated but in the caption to Fig 2 it says 36 earthquakes (and 9 blasts).

[Reply] We have two different databases for relocation (34 earthquakes) and tomography (36 earthquakes and 9 blasts). For better understanding we have redrawn the Fig.2.

It would also be interesting to know why the authors did not attempt detection of more

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events as they had access to a much denser network than the permanent Swedish and Finnish networks and therefore should have been able to detect smaller events.

[Reply] The equipment for the POLENET/LAPNET array was provided by several research organisations. That is why at many of the stations the sampling rate was 40 sps and 50 sps only, and it could not be increased because of the equipment limitations. This sampling rate was not enough for detection of smaller local earthquakes.

2) Relocation.

[Reply] We added columns with the number of observations in permanent and temporary stations and with the name of nearest station to emphasize the importance of POLENET/LAPNET data for this relocation.

The results of the two different methodologies are compared, but no comparison is made to the original catalogue locations.

[Reply] We inserted columns with origin time, coordinates and depths from FENCAT in Table 3. Also we performed comparison with the FENCAT in the text.

The uncertainties in the various locations, original and relocations, need to be discussed in more detail to determine the accuracy of the locations. The uncertainties tabulated in Table 2 and 3 (g_er and v_er) and the factor 0.53 are not well explained and should be made clearer. Which method do they come from?

[Reply] We have added the text about estimated standard error of arrival times and the weight code assigned to each arrival time. The factor 0.53 connects the uncertainty at the 68% confidence level and the maximum deviation. The maximum deviation of the 68% joint confidence ellipse in the x direction is equal to the square root of the ratio of the 68% value of chi-square with three degree of freedom to the 68% value of chi-square with one degree of freedom. We agree that the explanation of the uncertainties tabulated in Table 2 and 3 (g_er and v_er) is difficult for understanding and replaced them with the uncertainty at the 68 % confidence level (σx= g_er, σz= v_er).

Synthetic comparisons of the methods should also be made so that it is clear what differences come from the methodologies themselves.

[Reply] We have performed three synthetic tests in order to compare the methods: the first one for error free data, the second one for the data with a 0.1 s standard error and the third one for the data with a 0.3 s standard error. The results are presented in Table 1-3 (supplement). After inversion of arrival times with a 0.3 s data error the RMS error varies between 0.13 and 0.21 s. The maximum deviation from the true depth equals to 9.5 km and corresponds to non-stable solution. The deep events have the stable hypocentre parameters after relocation. In our study we made comparison of the methods using the "master events" from the Hukkavaara hill.

It is strange that the authors see no benefit in using S-phases in the locations.

[Reply] We have performed the relocation using also the first arrivals of S-phases.

A plot of the depth distributions before and after relocation would be valuable.

[Reply] We analyzed depth distribution before and after relocation in supplementary figure 1-2.

And how well constrained are the depths? Table 3 indicates (depending on the exact meaning of v_er) that the depths obtained by the different relocation methods sometimes vary more than v_er.

[Reply] For event on 070609 at 02:52 with ML=1.7 with depth of 53 km we present the comparison of observed travel time with the theoretical travel time of direct P and S waves (Fig.9, main text). We observe very big scatter of both P and S wave first arrivals. The mistake connected with erroneous determining of time was excluded because of very sharp impulsive arrivals. The possible explanation is the difference in velocity models beneath different groups of stations. This earthquake is situated near the end of the Palojärvi, Paatsikkajoki and Kultima fault system. Analysis of seismicity map from (Korja, Kosonen, 2015) shows that one deep earthquake was observed earlier

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from the same the postglacial fault branch. Also in Table 3 the stars are denoted the events with one and more stations satisfying the condition Δ<2*depth. For these events we expect more reliable determination of depth. Also in supplementary figure 3-4 the relation between the depth and its RMS are presented for investigation of the depth stability.

3) Local event tomography. The authors do not state how many phases from earthquakes and blasts are included in the velocity estimations, except that in their VELEST runs they had a total of 624 rays.

[Reply] We used only times of first P arrivals, 624 rays for VELEST and 621 rays for SIMULPS14. Added in main text " VELEST run with a total of 36*4+9+50+2=205 unknowns and 624 rays: 311 direct and 313 refracted , the over-determination factor of the inverse problem is approximately 3. The maximum number of hypocentres (25) is located in the layer 1.3 -18 km "

The events are not included in the resulting velocity plot sections which makes it difficult to assess the results.

[Reply] We included the events relocated in 3D model in the resulting velocity plot sections (Fig.16, main text) in accordance with its depth: section at 1.8 km shows events with depths less than 6 km (filled circles - earthquakes, blank circles – explosions), section at 10 km contains events with depths between 6 and 14 km, section at 18 km contains events with depths of more or equal to 14 km. We have also added the map of ray trajectories (Fig.13, main text) and khit map (analogue of the ray density map for blocks, Fig. 5 supplement). Also in supplement (fig.6, suppl) we drew the map of events before relocation and after.

The station corrections from VELEST are compared to topography in Figure 12 and the authors infer a dependency of the statics with topography. Is elevation not included in the VELEST runs? VELEST has various ways to account for uneven station elevations, this should be described by the authors. Could the corrections not be from velocity

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variations?

[Reply] The elevation corrections were applied in a standard way in VELEST. We showed the comparison of station corrections with topography, because station corrections can be considered as an additional source of information about the region under study.

The description of the parametrization of the tomography models is unclear to me, how many cells are there in the models, are the events relocated in the tomography and how many unknowns does this add up to? This should be compared to the number of data.

[Reply] Initially, the model cells were 50*30 km. Then the cells were enlarged to 70*50 km in order to increase the over-determination factor. In process of revision of the manuscript we varied damping of velocity adjustments and hypocentre parameters, minimal number B spline coefficient that is used for fixed grid point (khit), weight of shot data relatively to earthquake data (wse). We found that after the increment of wse the resolution capability is increased. In Fig.16 (main text) the RMS data misfit decreased from 0.32 s to 0.27 s in normal grid and from 0.32 s to 0.25 s in rotated grid. After relocation the maximum vertical deviation equals to 5 km, the maximum horizontal deviation equals to 3 km (Fig.6, suppl). We have redrawn Fig.14, Fig.15, Fig.16 and added new Fig, 13 (main text), changed text in chapter Local event tomography, added the correspondent text in Discussion and conclusions. In SIMULPS14 the linear B splines are used for parametrization. For description of 3D velocity function in one point coefficients connected with 6 B splines are required. Spline presentation of function enables continuity of this function. Generally, the condition of continuity helps to receive better results than block parametrization. For better understanding of parametrization we present khit map (Fig. 5, suppl). In contrast to VELEST and PStomo_eq (author Tryggvason) the separation of variables is used in SIMULPS and Sphypit90 (author Roecker). Relocation of events and velocity reconstruction are performed consecutively in SIMULPS and Sphypit90 although hypocentre and velocity variables are found simultaneously in VELEST and PStomo_eq. In our case total number of rays equals 621, hypocentre variables are 36*4+9=153, the velocity adjustments are 299 and over-determination factor equals to 1.6. We understand that this is very small over-determination factor, but the aims of present research was to recover major 3D velocity heterogeneities. The tests of ray coverage (checkerboard tests) confirm the possibility of using this data. In the future the data set may be complemented by arrivals from permanent stations for longer time period and temporary stations in Finland and in Sweden.

The checkerboard tests are done with large cells of 75 km to 150 km, but from the results in Figs 13-14 it seems that the model grid is much finer? On pg 3700, line 19, it seems like the grid may be 50x30 km, but this is difficult to reconcile with Figs 13-14, and seems odd if the checkerboard variations is on a 75x75 km scale?

[Reply] Indeed we reconstruct variations of 75x75 km scale with help of grid 50x30 km. The good result is connected with the B spline parametrisation ensuring the continuity, with using of several B splines for calculation of velocity in particular point. In a new version of manuscript we increased the grid to 70 x50 km. In Fig.14 we see bad reconstruction of checks with size of 75x75 km and more good reconstruction of checks with size of 100x100 km.

The checkerboard tests seem to indicate that the tomography works well with velocity heterogeneities of 75x75 km, and there is no difference if the grid is rotated to 30 degrees. However, in the results in Fig 15 there is a clear dependency on the grid direction, in 15 a) there is horizontal smearing but in 15 b) the smearing is at 30 degrees. Why is this? How does the smoothing work in the tomography?

[Reply] We agree that our test concerned the rotation in 30 degrees is obscure and we have reworked it. In new version (Fig 15 a and b) we initially show difference between reconstruction of one model for different grids (normal and rotated grid), then (Fig.15 c and d) we show difference between reconstruction of another model for different

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grids (normal and rotated grid). Also we show the character of reconstruction when boundary of discontinuity coincide with the grid lines in direction and when boundary of discontinuity is oblique relative to grid line (in Fig 15 a and d – coincide and in Fig 15 b and c – not coincide). As a first result the present experiment geometry allows different reconstruction of velocity model for different grids (comparison of Fig 15 a and b or Fig 15 c and d), but shows the same major velocity features. As a second result of the test the true position of the discontinuity is determined better when the boundary of discontinuity coincides with the grid line (comparison of Fig 15 a, d with Fig 15 b, c). In our study four iterations were calculated. The damping is the same for all iterations and the maximum deviation from initial velocity was fixed to the value of 0.2 km/s in each iteration.

4) Discussion and conclusions

The authors draw conclusions that in some cases are not well based on the data. On page 3702, line 18-19 they state that the results of the study "...provide new knowledge about the processes that cause intraplate seismicity in northern Fennoscandia." Causative processes is however not treated in the manuscript.

[Reply] In our study we mainly investigated the spatial correlation between structures that could be reactivated in a present-day stress regime and hypocentres of local earthquakes. The processes responsible for reactivation are out of scope of our study. We corrected this sentence respectively.

Pg 3702, line 21-23, "The lateral heterogeneities in the upper crust in our velocity model are show general good correlation with the surface geology" This is difficult to assess from Figs 1b) and 15. Perhaps the velocity models could be placed transparently on top of the geology? Statements on page 3703 also indicate mismatch at the Finnish-Swedish border.

[Reply] Comparison of velocity heterogeneities and boundaries of the geological units is presented in a new Figure 16.

Pg 3703, lines 16-19. This sentence is unclear, what is the role of the tomography results here? Pg 3703, lines 20-24. That the earthquakes show good correlation with postglacial faults was shown very clearly by Lindblom et al. (2015). That study also indicated that there is less of a north-south directionality in the seismicity, along the BBMS, than there is a NE-SW direction, in line with the PGFs. This is also indicated in the FENCAT data shown in Fig 16 in the manuscript. The 34(36) earthquakes in this study do show a north-south pattern, but could that be an artifact of too sparse data? In addition, this manuscript does not show a correlation between seismicity and PGFs, as the PGFs have not been drawn in Fig 2 and in Fig 17 the deep events are mostly unrelated to the mapped PGF scarps.

[Reply] This comment is probably because of some misunderstanding. We do not state that the epicenters show the N-S trend, but that the postglacial faults in the region are located within a N-S trending zone (BBMS). The individual faults may be oriented differently. We corrected the text to avoid this misunderstanding.

Pg 3704, lines 1-10. It is a little unclear if the authors mean that the Lainio-Suijavaara (note spelling) and Lansjärv faults are in the BBMS. As defined by the authors in Figs 16-17, the Lansjärv fault is not in the BBMS and only part of the Lainio-Suijavaara fault is in the BBMS. As there have been deep earthquakes on the Lansjärv fault (34 km, Arvidsson 1996), the Pärvie fault (35 km, Lindblom et al. 2015) and the Burträsk fault (>30 km, Juhlin & Lund, 2011), the statement on lines 5-6 is incorrect.

[Reply] the sentence was removed and references to Lindblom et al. (2015) and Juhlin and Lund (2011) were added.

Pg 3704, lines 15-17. Arvidsson (1996) discussed the large postglacial earthquakes 10,000 years ago, which occurred just as the ice sheet disappeared. He did not refer to the current seismicity. Pg 3704, lines 18-20. The World Stress Map 2008 does not show faults, but for northern Fennoscandia has 4 thrust faulting stress indicators, 1 normal faulting indicator and 5 indicators of stress direction but not regime. In addition, the remaining rebound stresses are very small today so these stress indicators are unlikely to show rebound stress.

[Reply] we have made the correspondent changes to the text.

Pg 3704, lines 21-26. It should be pointed out that in the Steffen et al. (2014) modelling paper a fault dipping at 75 degrees is only activated if the assumed coefficient of friction in the rock is very low (mu = 0.2), a value which is likely to too low in the Baltic Shield. In addition, the manuscript has not shown that the deep earthquakes occur at the PGFs, on the contrary, Fig 17 indicates that the deep events in this study occurred away from the PGFs. Finally, Steffen et al. (2014) have reverse faulting mechanisms in their model events, which is not in agreement with the strike-slip events of this study.

[Reply] the text of this paragraph is changed.

Pg 3704 - 3705, lines 27-28 + 1. The earthquake activity along the Swedish-Finnish border, or the BBMS, is a well known and described feature in Fennoscandian seismology. This study does not show that the seismicity here is deeper than on the PGFs.

[Reply] the text has been changed as proposed by reviewer.

6) Additional references. Much work has been done lately on the issue of postglacial faulting (PGF) and seismicity in connection with PGFs. The authors should update their maps with the fault scarps from Sutinen et al. (2014) and Mikko et al. (2015). Lindblom et al. (2015) presented the full earthquake data set in northern Sweden and its relation to PGFs, and a special earthquake study on the Pärvie fault. This paper is especially significant for the manuscript here as it is likely that most earthquakes that this manuscript locates in Sweden are part of the data set used by Lindblom et al. (2015). PGFs and seismicity in Fennoscandia was discussed extensively in Korja and Kosonen (2015). Redfield and Osmundsen (2013,2015) presented a model for the Fennoscandian seismicity based on hyperextension and Bungum et al. (2010) discussed tectonic versus rebound driving mechanisms.

[Reply] We have added the references as proposed. However, the Pärve fault is located outside our study area, that is why the results of Lindblom (2015) for the Pärve fault cannot be compared directly to the results of our study.

Smaller issues: - The language needs polishing, especially the use of "the" and "a".

[Reply] Corrected.

- Pg 3690, l 22: "shift" and "uplift" are not usually used for focal mechanisms. The sentence can be ended after "... strike-slip type."

[Reply] We have removed “in which shift prevails over uplift”.

- Pg 3690, l 22-24: The BBMS is well established as seismogenic before this study.

[Reply]: in our study we used new experimental evidence to confirm this. One need to remember that seismicity in the intraplate regions is low compared to the active areas, that is why any new experimental evidence is important.

-Pg 3691, l 3-4. For what purpose(s) are the permanent seismic networks not dense enough? It should be pointed out that the Swedish and Finnish seismic networks have expanded significantly in the last 10-15 years, also in the north. See Korja & Kosonen (2015)

[Reply]: the density of permanent seismic stations in northern Finland is still not sufficient. That is why enhancement of the permanent seismic network will be done in 2015-2017 in the framework of EPOS (European Plate Observing System) project.

-Pg 3691, l 10-11. None of these references studied local earthquakes.

[Reply] Corrected.

Pg 3691, l. 21. There are no organizations in the Acknowledgment, only persons. For this study, the data from the Finnish and Swedish seismic networks should be acknowledged.

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[Reply] We have corrected Acknowledgment.

-Pg 3692 l. 8-10. The Arvidsson (1996) study does not talk about current seismicity, and the Wu et al. (1999) study concerns GIA modelling. Other papers should be quoted here, such as Slunga (1991), Bungum et al. (2010). Redfield & Osmundssen (2013,2015) etc.

[Reply] The references were added as proposed.

-Pg 3692 l. 11-12 A more recent reference is Lidberg et al., J. Geodyn. (2010).

[Reply] We changed the text: According to Lidberg. (2010), the maximum vertical velocities in the post-glacial uplift area are observed at 19.50E/63.60N. In our study region the vertical uplift rate is ranged from 7.7 mm/y to 9.9 mm/y .

-Pg 3692, l. 13-15. These references should be changed to Kujansuu (1964), Lundqvist & Lagerbäck (1976) and Olesen (1988), or the more recent Kuivamäki et al. (1998), Lagerbäck & Sundh (2008) and Olesen et al. (2004).

[Reply] Referenced have been changed.

-Pg 3692, l 16-20. Add Olsson et al. (2008) and Eken et al. (2007).

[Reply] Corrected.

-Pg 3693. The introduction should have a paragraph on the results in Lindblom et al. (2015) as they are important for this study.

[Reply] We have inserted.

Section 2.

-Pg 3693, l 22. The Helsinki catalogue is commonly referred to as FENCAT and not HEL, as it has data from all the Nordic countries.

[Reply] We have corrected.

-Pg 3692, l. 25-27. It would be good to write out where these locations are, and what activity goes on there. Quarries in both locations?

[Reply] We have detected 5 clusters. All clusters are identified as quarry with help of Google Earth. One cluster is around 67.90N and 25.40E (Kittila gold mine, ∼200 events), the other cluster is around 67.80N and 20.20E (Kiruna, ∼3000 events), the third cluster is around 67.10N and 20.90E (quarry is visualized with help of Google Earth, ∼4000 events), the forth cluster is around 67.30N and 30.40E (Kovdor, ∼400 events), the fifth cluster is around 69.40N and 30.80E (Zapolyarni, ∼400 events).

-Pg 3694, l 11-14. Could this be radiation pattern effects? There are only 2 stations closer than 100 km in the figure, and some of the more distant stations also have relatively small P.

[Reply] Yes. This may be effects of radiation pattern.

Section 3. The purpose of this section is a little unclear as it is mostly related to velocity models and not picking as such. The authors discuss phase arrivals from various discontinuities and in terms of phase identification this is important, but perhaps less so in terms of picking the first arrival. The authors do not state if they use classifications of the arrivals in terms of how clear they are, or if they can associate uncertainties to the arrivals. I find this section unnecessary long.

[Reply] We have joined the chapters “Data” and “Picking . . .” and named it “Data and velocity model”. Also we have shortened the text.

-Pg 3694, l 21-23. Which layers were merged, and how?

[Reply] We have added “Two upper layers were replaced to one because of its small thickness (0.5 and 0.8 km).”

-Pg 3695, l 1. For shallow events the take-off angle is always greater than 90 degrees.

[Reply] We corrected the text.

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-Pg 3695, l 17-18. What do you mean by "Particular analysis..."?

[Reply] Particular analysis is the comparison of observed and calculated reduced travel times graphically and the revealing of the erroneous determinations.

-Pg 3695, l 27-29. This of course also depends on the velocity model.

[Reply] Yes. The location depends on the velocity model.

Section 4. -Pg 3696, l 15. What is meant by the "method is uniform for arbitrary complex velocity models"?

[Reply] The complex velocity model is the laterally heterogeneous model with break points of any kind. For this method there are no restrictions in property of velocity function.

-Pg 3696, l 20. Why such a large model? 800x800 km? You only use stations out to 250 km.

[Reply] We have changed the model size to 500x500 km

-Pg 3696, l 22. What is "short distance conversion"?

[Reply] The short distance conversion is very simple transformation (lat,lon,depth) to (x,y,z) that is often used in teleseismic and local tomography (Waldhauser et al., Geophys. J. Int., 2002, 150, 403–414; Sandoval, DISS.ETH NO.1468) and also in tomographic program (Simulps14, subroutines latlon, setorg; Sphypit90 subroutine distsph2). The latitude is recalculated from geographic to geocentric. Then on the plane we determine the centre of coordinates (lat0,lon0) that is conformed in (x=0,y=0). For the case without rotation relatively North direction x=(lon-lon0)*111*cos(lat0), y=(lat-lat0)*111. Then for velocity and depth we perform earth-flattening correction R to z and vsp to vpl.

-Pg 3697, l 29-1. The events in FENCAT are usually well investigated with respect to blasts. Do you have other indications except for the depth that these are blasts? Have

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you looked at polarities and spectrograms?

[Reply] Analysis of spectrograms is used routinely in order to distinguish natural events from the blasts. We have replaced in Table 3 name “Probably explosion” in “Events near the surface”. For the Referee we have prepared a supplementary Figure 7-8 with waveforms and spectrograms for these events. For event 12.11.2007 03:37 UTC the first P wave arrivals correspond to impulsive dilatations on RNF (Δ=8km) and LP21 (Δ=80 km). We may say that our data for these events are more complete than those used in FENCAT. For event on 12.11.2007 at 03:37UTC in FENCAT very big residuals for nearest station RNF (resp=-1s, ress=-1.3 s, Δ=8km) are observed. For this event in FENCAT the Gap value equals to 155, while in our investigation the gap equals 56. The second station SGF is situated at the distance of 91 km in FENCAT, in our work between RNF and SGF we have 5 stations: LP33 (Δ=73 km), LP31(Δ=79 km), LP21(Δ=80 km), LP41(Δ=80 km), LP12 (Δ=90 km). S waves are identified not clearly.

-Pg 3698, l 4-5. The station distribution, and higher density, surely plays a role here?

[Reply] Yes. We have corrected the text.

-Pg 3698, l 10-11. It is the maximal gap, not The minimal angle... I presume?

[Reply]We have changed the text.

-Pg 3698, l 12. Ref to Fig 17.

[Reply] Changed.

Section 5. -Pg 3699, l 27-28. Why is the N-S nodal plane the most likely fault plane?

[Reply] In the chapter Focal mechanisms . . . we have written: As follows from the strike the direction of the fault plane is deviated 00-200 from the N-S direction clockwise or the direction is NWW-SEE.

-Pg 3700, l 1-2. What do you mean by fault stretching in longitude direction?

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[Reply] The longitude direction is the direction E-W.

-Pg 3700, l 3. Remove ... which shift prevails over uplift.

[Reply] Removed.

-Pg 3700, l 4-7. This information is redundant and can be removed.

[Reply] Removed.

- Fig 17. The focal mechanisms here is a subset of available mechanisms in northern Fennoscandia, and they are generally more varied than the strike-slip events shown here. See e.g. Korja & Kosonen (2015), Arvidsson & Kulhanek (1994).

[Reply] We determined coordinates of Region 2 as 22.0-26 E, 66.5-69.0 N. For this region we chose all earthquakes with focal mechanisms from Table 4.3.1 in Korja & Kosonen (2015). The total is 10 events. We denoted 4 from 10 in the Fig.18. In process of correcting we added the rest 6 beach balls.

Section 6. -Pg 3700, l 12-13. Did you use VELEST without relocating the events in the new 1D model?

[Reply] No. Added ... and relocating the events in the new 1D model...

- Pg 3701, l 1. Table 5 is a little unnecessary as the change is very small. This could be stated in the text instead.

[Reply] Removed Table 5, added "The maximum number of hypocentres (25) is located between 1.3 and 18 km . " and "Final velocity values in these layers are changed less than in 0.1 km/s from initial. So the main decreasing of RMS is connected with the time station corrections.

Tables

2) How come the second event has a station as close as 25 km and the others do not?

[Reply] Station LP62 (Δ=25 km) was installed 05.09.2007, LP63 (Δ=59 km) was in-

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stalled 27.09.2007, LP71 (Δ=78 km) was installed 26.09.2007. For the explosion on 16.08.2007 this stations did not work, but for explosion 24.08.2008 LP62 worked. We have corrected the table with regard to S arrivals. Also we have added the text relatively different gap and different Δ for different explosion. These different variants of gap and Δ are good for testing.

5) This Table is not necessary seeing how small the differences are.

[Reply] We have deleted the table.

Figures 1) Add a larger scale insert to show where the study area is located in Fennoscandia. Indicate which stations are permanent and which are temporary, perhaps with different symbols. Spelling: Lainio-Suijavaara, Lansjärv, Suasselkä. Write Blue boxes. The ref to the faults should not be Muir Wood as they were described by other people. See similar comment above for page 3692.

2) Add the faults to the map. Use unfilled symbols to make it easier to see. Use FENCAT instead of HEL.

[Reply] We have done all.

3) These are too small, it is very difficult to see the text. Why use the FENCAT distances (delta) and not the relocations?

[Reply] We have enlarged waveforms. We use FENCAT distances for simplicity of reading. In the initial part of article till explanation of used location methods it is logical to use the generals data. Also according Fig 1 (suppl) and Table 3 (main text) the relocation coordinates and FENCAT coordinates are close.

4-5) Write that these are the first arrivals.

[Reply] We have written.

6) What are the distances to the stations from the event?

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[Reply] We have added.

8) This figure is not much discussed and can be removed.

[Reply] We have removed Fig.8.

10) This is not an essential figure as onset uncertainty is not discussed much. How are the traces filtered?

[Reply] We would like to remain this figure for additional argument of reliable in our focal mechanism solution. The filtering is not essential in this figure, but we used the standard WWSSN-SP filter from Seismic Handler.

13-15) The green lines outlining the well resolved region are hard to see.

[Reply] Corrected.

17) In Table 3 there are 7 deep events. Here only 6?

[Reply] Corrected.

Please also note the supplement to this comment:
http://www.solid-earth-discuss.net/7/C2023/2016/sed-7-C2023-2016-supplement.zip

Interactive comment on Solid Earth Discuss., 7, 3689, 2015.