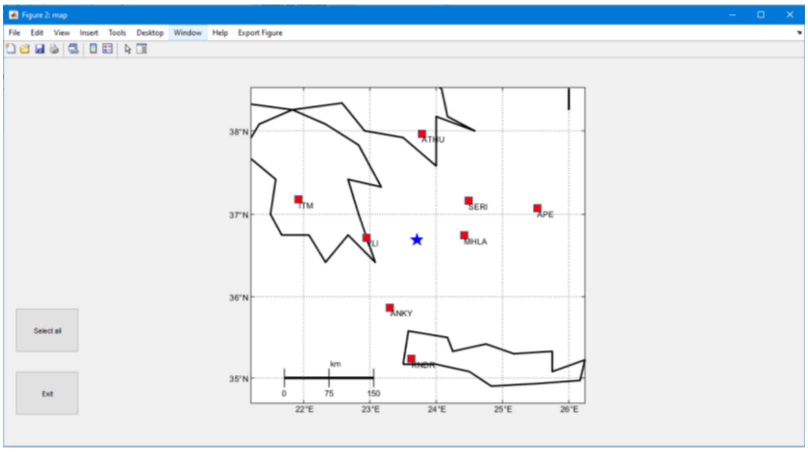
Example 05
Peloponnese, aftershock Mw 4.7 of the earthquake from Example 04. Inversion of waveform envelopes.

Before this, see the introductory hints in isola_EXAMPLE_01.

Preparation
Event Info. We study a real relatively small (M 4.7) event of 20140829 at 03:48:36.00 UTC, located by NOA at Lat 36.69, Lon 23.7093, depth 90 km (an intermediate-depth event, the **only aftershock** of the earthquake studied in Example 04). We choose again TWL= 409.6 s.
Station Selection. Taking 8 stations, i.e. all from the file network_aftershockNO8.stn, saved in the root. Select all. Then Exit.



Define Crustal Model. The same model as in Example_04.

Data Preparation. Copy the *raw.dat files from Example_04 into the invert folder, or use the spare folder isola_RAWdata_realNo8 here in Example_05.
Seismic Source Definition. Trial source positions below epicenter, starting at depth 90 km, depth step 5 km, 3 positions. Calculate and Exit. Data is saved in folder green.
Green function calculation. GF is calculated up to the Nyquist frequency 1.25 Hz, assuming delta-function moment rate (default values); 3 trial sources, 8 stations.

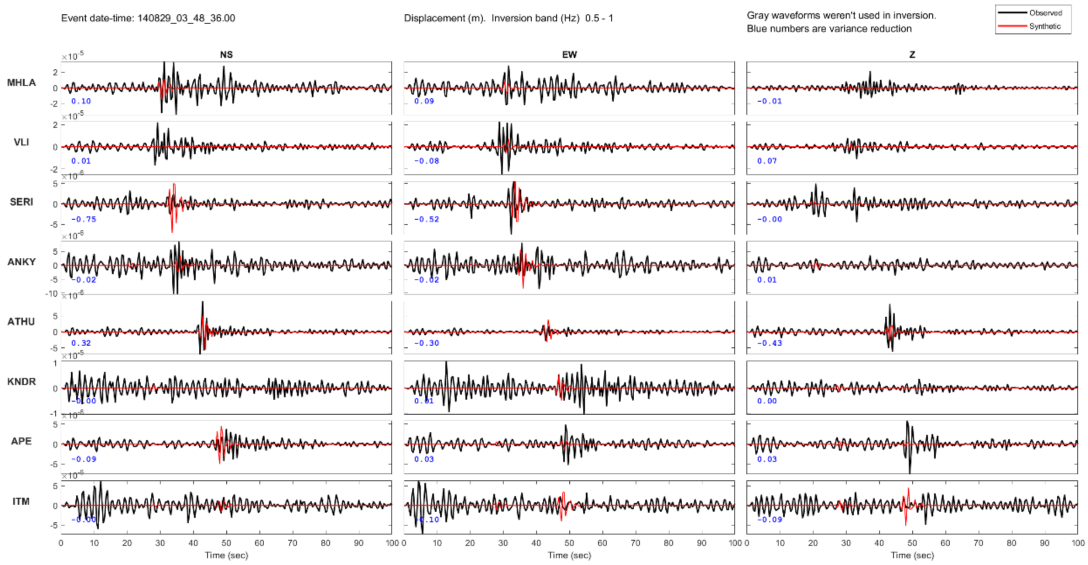
Test 0 Waveform inversion

The following *unsatisfactory* inversions are not saved.

Inversion, frequency range 0.02-0.10 Hz (common to all 8 stations). Time search -10 to +10 s, step 0.4 s. Choosing Full MT. Inversion with standard Isola. In the Windows command screen we see a variance reduction 1.68e-2 and in the waveform plot we see no fit at all. It is because, in this range (which was good for mainshock), we have no signal, just noise.

Inversion, frequency range 0.02-0.10 Hz as above, but with Isola_cova. Matlab command window gives varred_classical = 0.01495, varred_standardized = 0.028789. The "COVA stuff" is not a magic tool that always solves everything; here it simply does not help, varred increased a bit by standardization, but is too low.

Inversion, frequency range 0.5-1.0 Hz. Because the event is small, and the low-frequencies used above were too noisy, here we selected a much higher frequency. Anyway, using standard isola (no_cova), the variance reduction is still very low, 0.36602E-01, no fit at all:

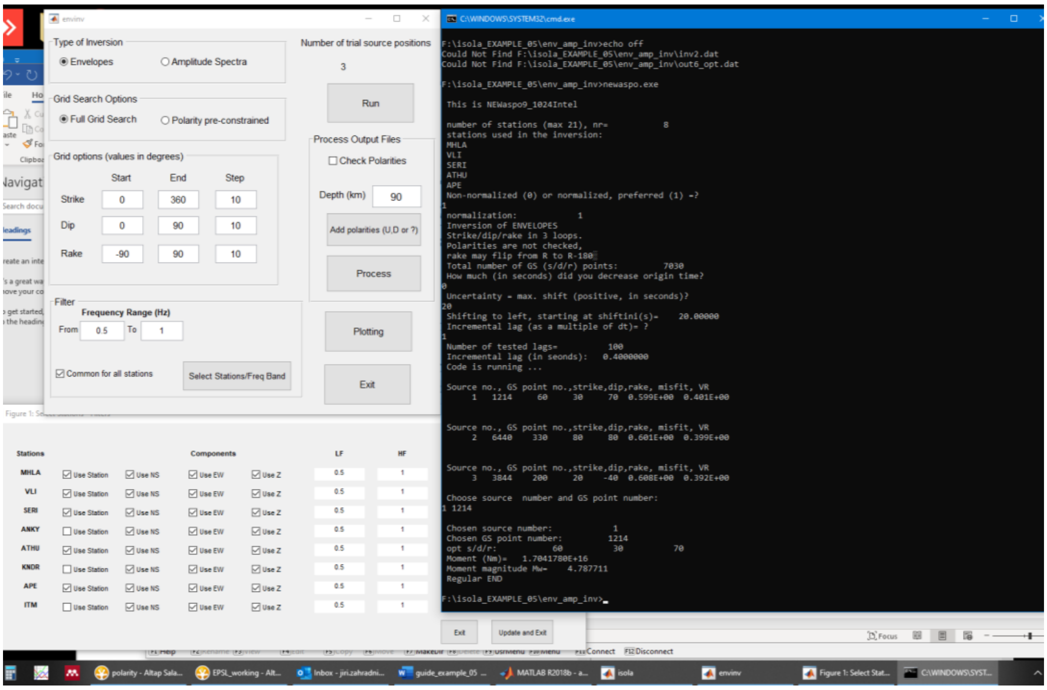


This calculation however suggests that in this frequency range, we are basically above low-frequency noise, the remaining problem is a high-frequency noise (stations ANKY, KNDR, ITM) and complexity of the wave field. Real wave groups, relatively well defined at stations MHLA, VLI, APE, are longer than synthetic groups, meaning that the velocity model is too simple and does not reproduce scattering. The waveform plot suggests that perhaps we could focus on inverting the relative strength of wave groups on different components, e.g. large observed amplitude on ATH-N and ATH-Z, and small amplitude at ATH-E, treating the group as a whole, not focusing on its individual 'oscillations'. This is the idea of fitting wave-group envelopes instead of waveforms. GUI has a special tool for this method; the 'button' Envelope inversion in the main menu.

Test 1 Envelope inversion with a few polarities

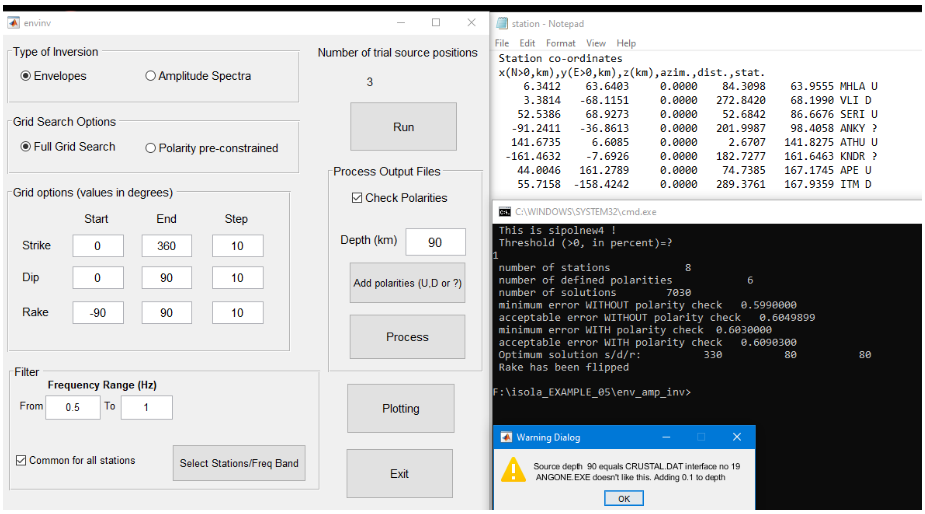
Before running this type of inversion, it is useful to check first-motion polarities because at least one polarity will be always needed when inverting envelopes. See folder polarity, and file readme there. In Test 1 we shall need polarities at some of our 8 stations, see the file station_polarity_8stations.dat, and how to implement them in file station.dat.

Now we open the Envelope inversion tool. If it was opened before, now it will closed and zipped: we start 'from the scratch'. From various options, we choose 0.5-1.0 Hz, deselect stations ANKY, KNDR, ITM (which are noisy), and Run. At the end of the run, monitoredin the Windows command window, we see that all 3 positions provide almost the same fit, formally we choose the first offered solution: 'source no. 1, grid search point no. 1214'

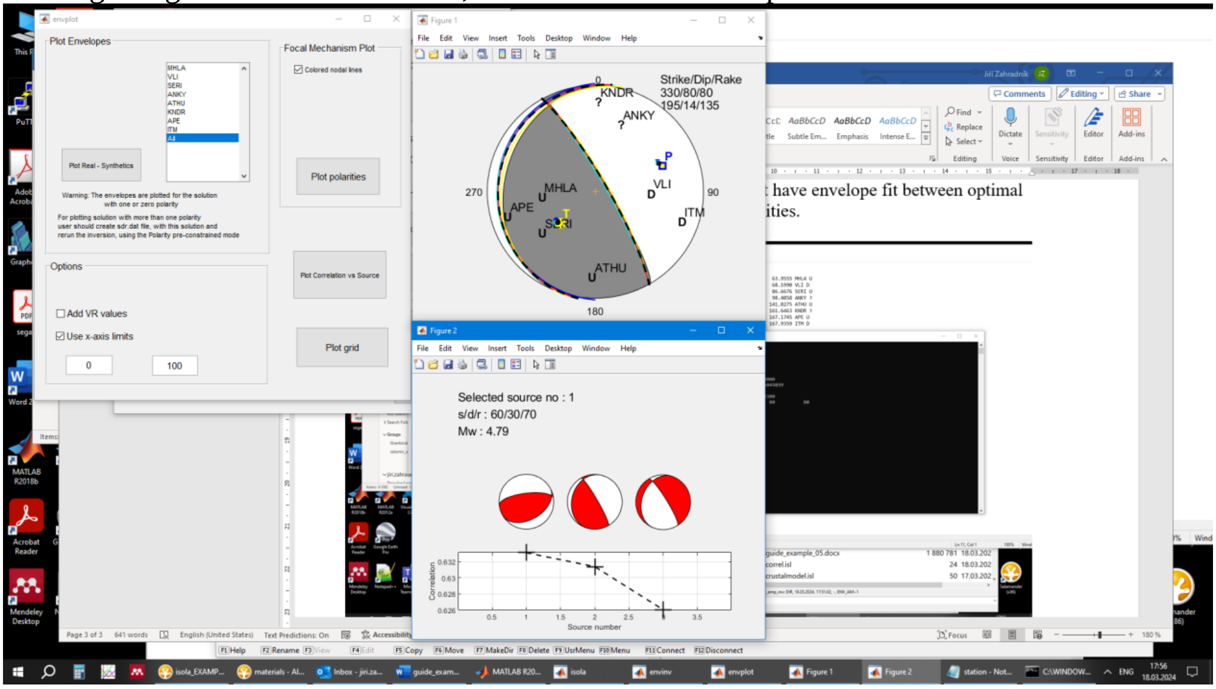


The first important result is that we estimated at least the scalar seismic moment and Mw:
Moment (Nm)=   1.7041780E+16
Moment magnitude Mw=   4.787711

Using the ‘button’ Add polarities we add U, D, ? to the stations (last column). Alternatively, we could copy the file station_polarity_8stations.dat from polarity folder into folder env_amp_inv as station.dat. We mark the box ‘Check polarity’, choose Process, and in the command window we prescribe a small threshold (e.g., 1.), meaning 1%, that is, we search for solutions that have envelope fit between optimal VRopt and 0.99 VRopt, and, at the same time, the solutions fit polarities.

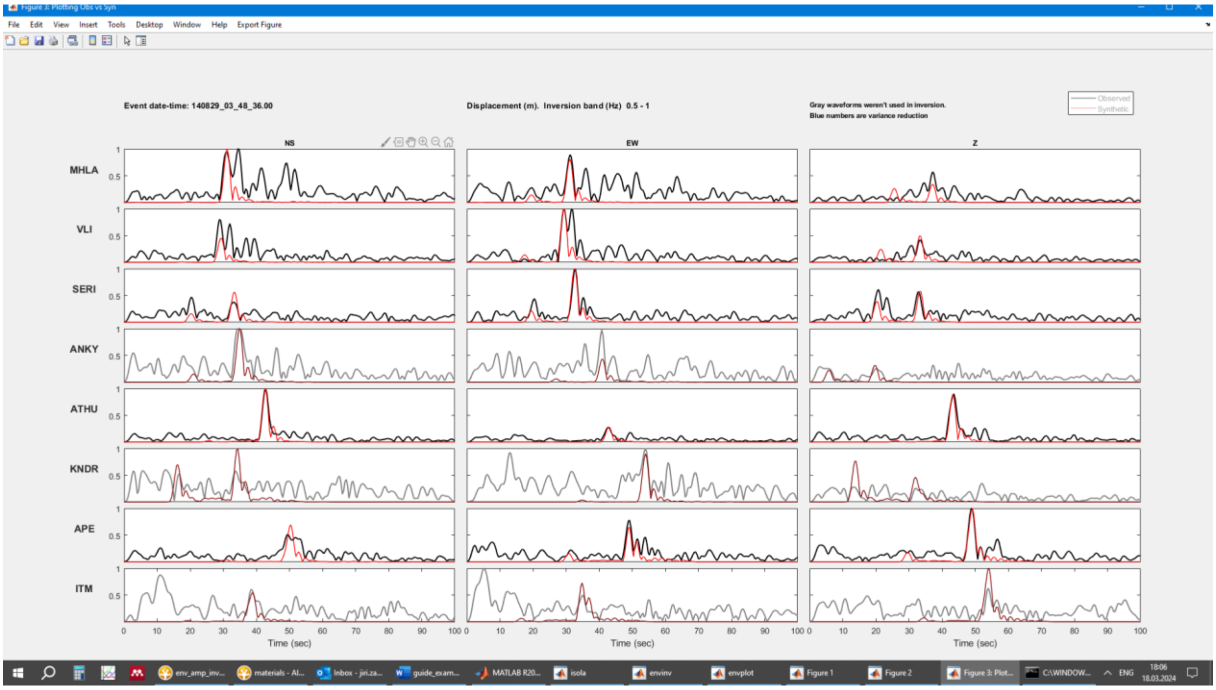


Plotting brings us to the next screen, where we choose Plot polarities and Plot correlation.



We find that polarities are fitted. However, the polarity beachball (gray, with stations) corresponds to the second ‘red beachball’, i.e. the second source number (although we have chosen the first one). It is because now we optimized the joint fit of envelopes and polarities. The solution of the resulting gray-shaded beachball (s/d/r 330/80/80) is also available in files out 1-5 and moremech.dat.

At this moment, it does not have much reason to use Plot Envelopes because it would display the best-fit solution of envelopes without considering the polarities (the left-hand red beachball which does not fit all polarities). Anyway, if we do that, we see that envelopes (without polarities) can be fitted very well:

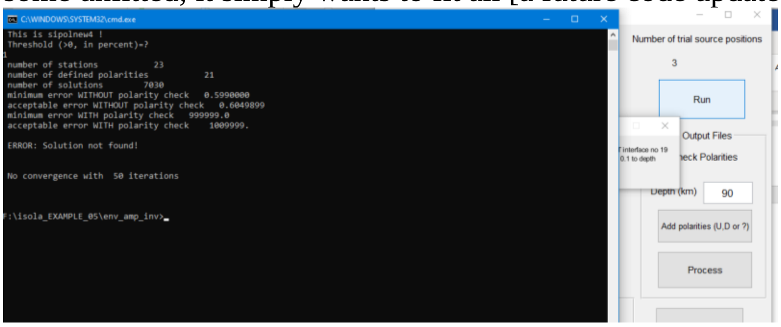


To get a plot of envelopes from the joint inversion of envelopes and polarities, we should do a trick. Before showing the trick, we add more polarities. Results up to here are saved in the root of Example 5 as Test1*.zip.

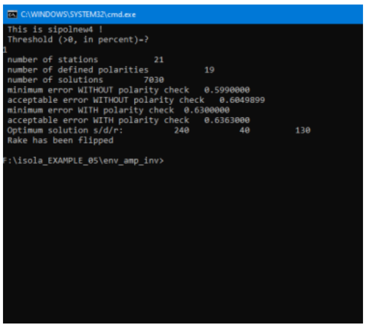
Test 2 Envelope inversion with many polarities

Now, for Test 2, we go back to the initial panel of Envelope inversion, make inversion as before and select source no. 1. Go to the polarity folder and see that there is a file called extrapol.pol. The file was made by making visual polarity readings at several stations of the network_HUSN.stn; you can check folder POLARITY_READING. Copy the file extrapol.pol to folder env_amp_inv. If you now click on Add polarities, you see not only your 8 stations at which you invert envelopes but also additional stations for which you added polarity.

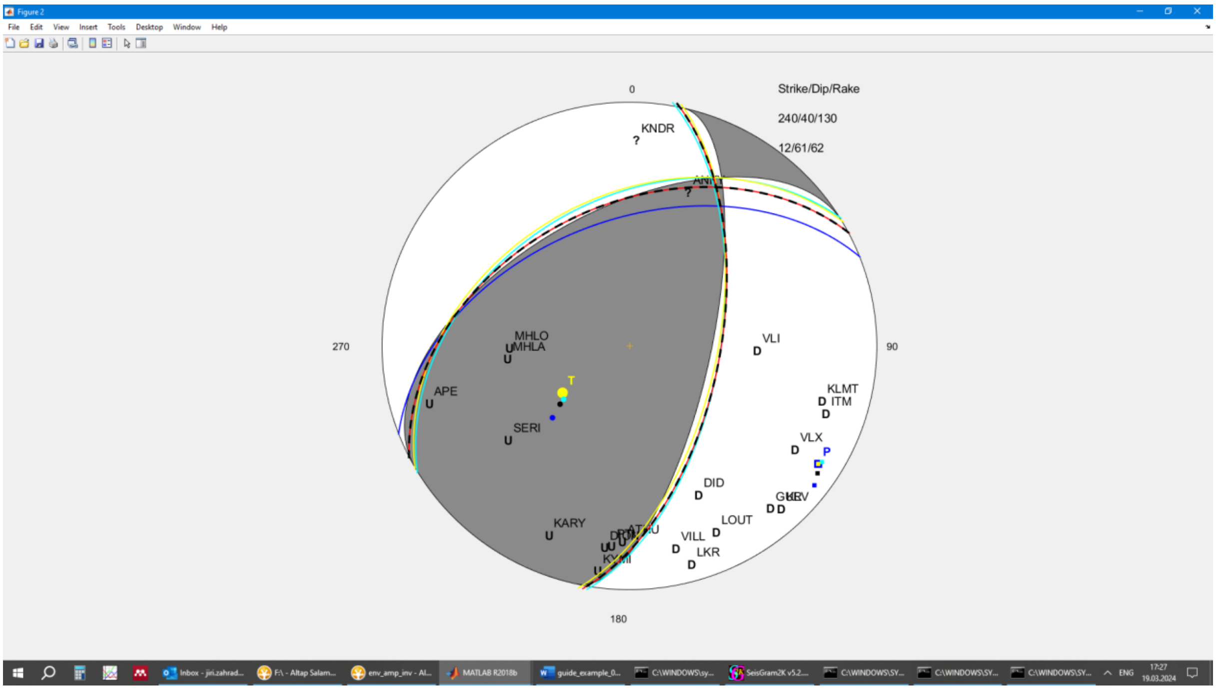
Continue with the button Process, choosing threshold 1 (percent) as before. Now, having many polarities, no surprise that you failed in fitting them, the screen says Error: no solutions found. The present simple code does not know how to fit some polarities and how to leave some unfitted; it simply wants to fit all [a future code update is of course needed here …].

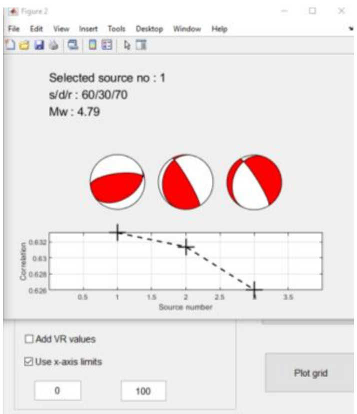


Do not continue with plotting! Instead, go to see out5_detail.dat, and you find (mainly at the end of this long file) that there are grid-searched s/d/r solutions which are violated by just two stations, KSTL and CMBO. Go to Add polarities, delete the rows corresponding to these two stations (in fact, CMBO could be retained and will not affect the results), save the file station.dat, Process, choosing 1% threshold and … now you succeeded! You fitted both envelopes and all polarities.



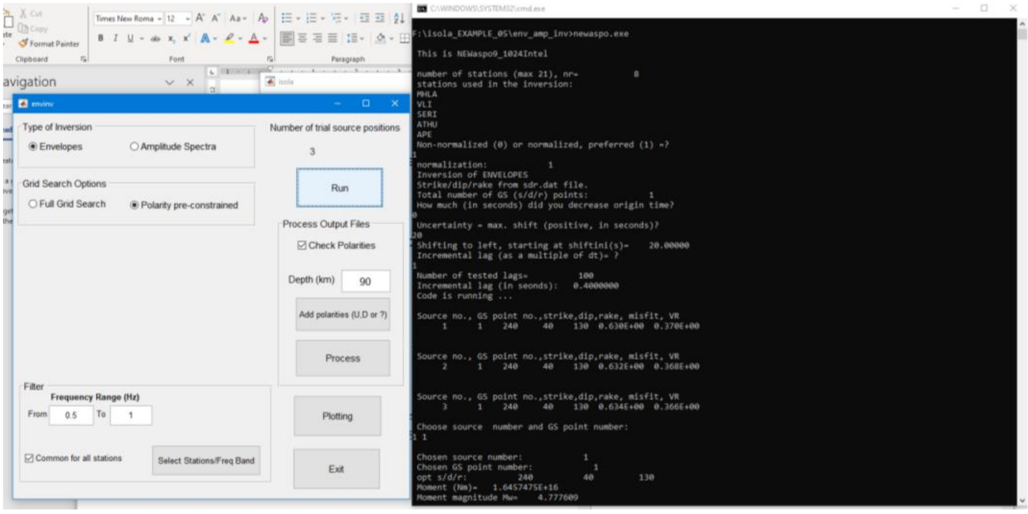
Proceed to the next screen (Plotting), Plot polarity, the solution has s/d/r = 240/40/130.



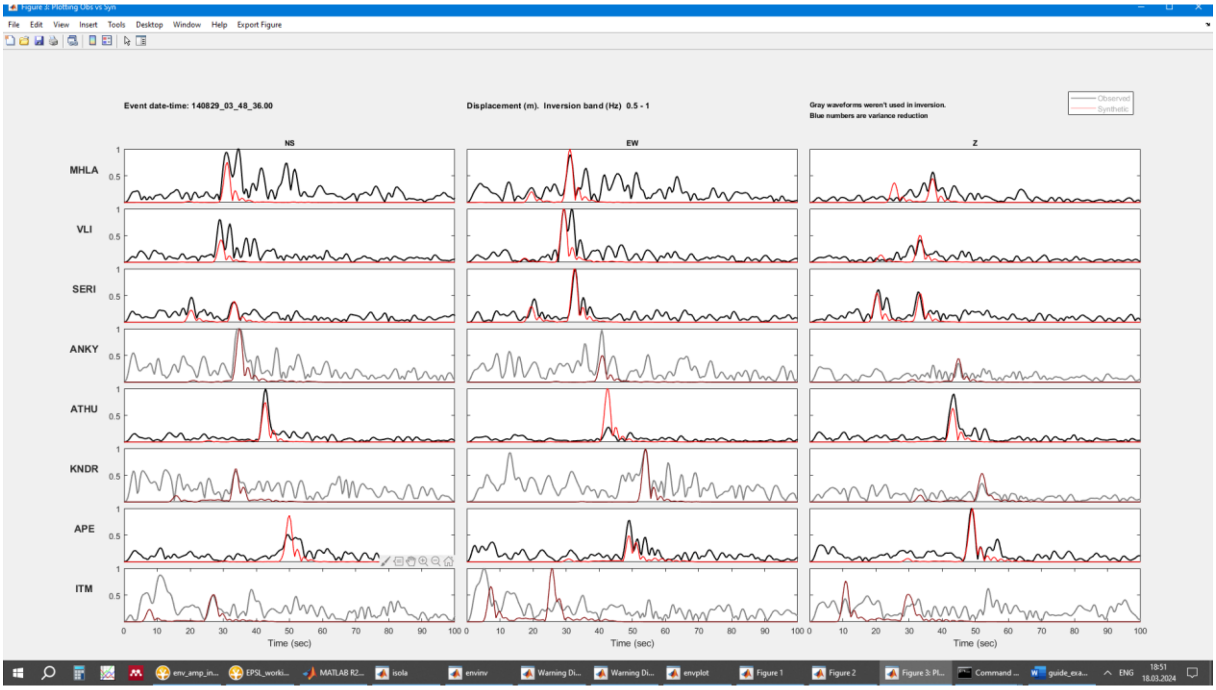


The solution with s/d/r = 240/40/130 is none of the three red balls. The red balls were optimal envelope fits without polarity constraint. You started from the left red ball, s/d/r = 60/30/70 (because its envelope fit was weakly preferable, it is position 1, depth 90 km), then you added polarities and ended with position 1 with s/d/r 240/40/130. If you choose Plot real-synthetic (envelopes) you would get the envelopes for the left red ball. This is not desired because it represents merely the optimum envelope fit, without polarities.

The trick. To plot envelope for the joint envelope/polarity inversion, with s/d/r =240/40/130, you have to do the following. Make a file sdr.dat containing just a single line 240 40 130 and put this file in folder env_amp_inv. Return to the initial screen and choose the inversion mode called Polarity pre-constrained. You will not make a grid search of s/d/r angles and you will obtain envelopes for the given fixed s/d/r values.



Go to Plotting, and, now you can get envelopes for s/d/r= 240/40/130. Overall, the solution is not bad, only ATHU-E is poorly fitted.



We have learned that for small events, when waveform inversion fails, some information about the focal mechanism can be obtained by combining envelopes and polarities.

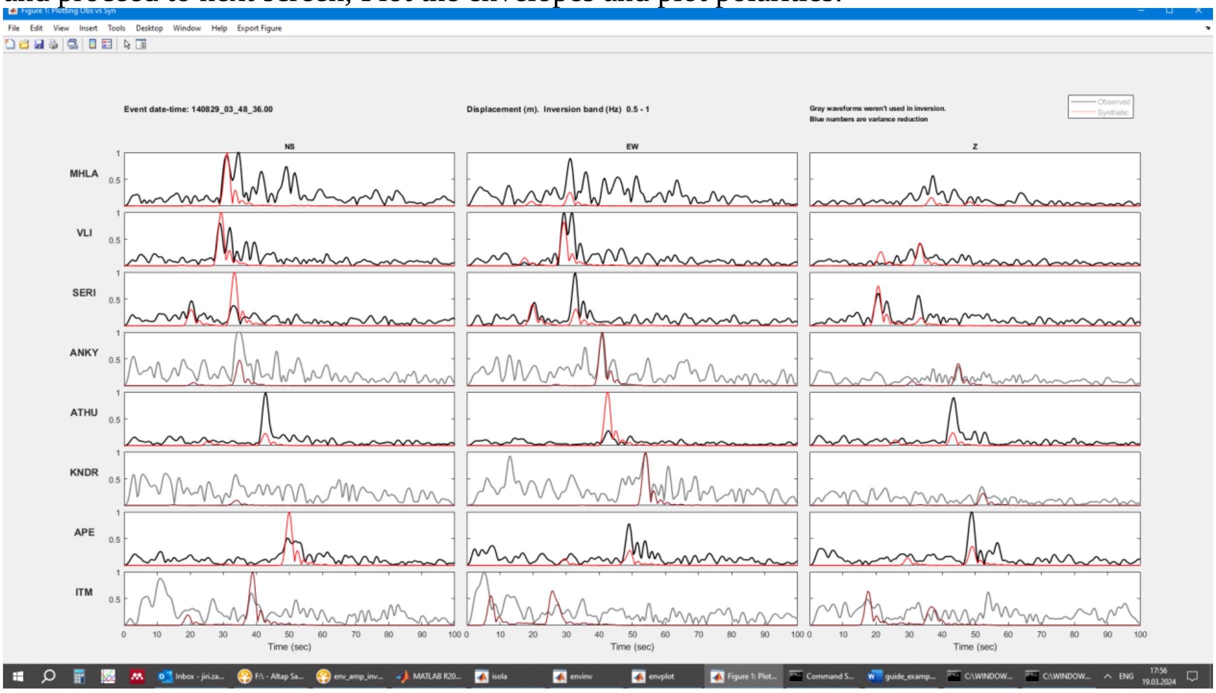
Now we can quantify how far the aftershock solution s/d/r = 240/40/130 is from the mainshock (for which we elsewhere, in Example 04, obtained s/d/r = 260/65/161). To this goal, open the Windows command screen and type:

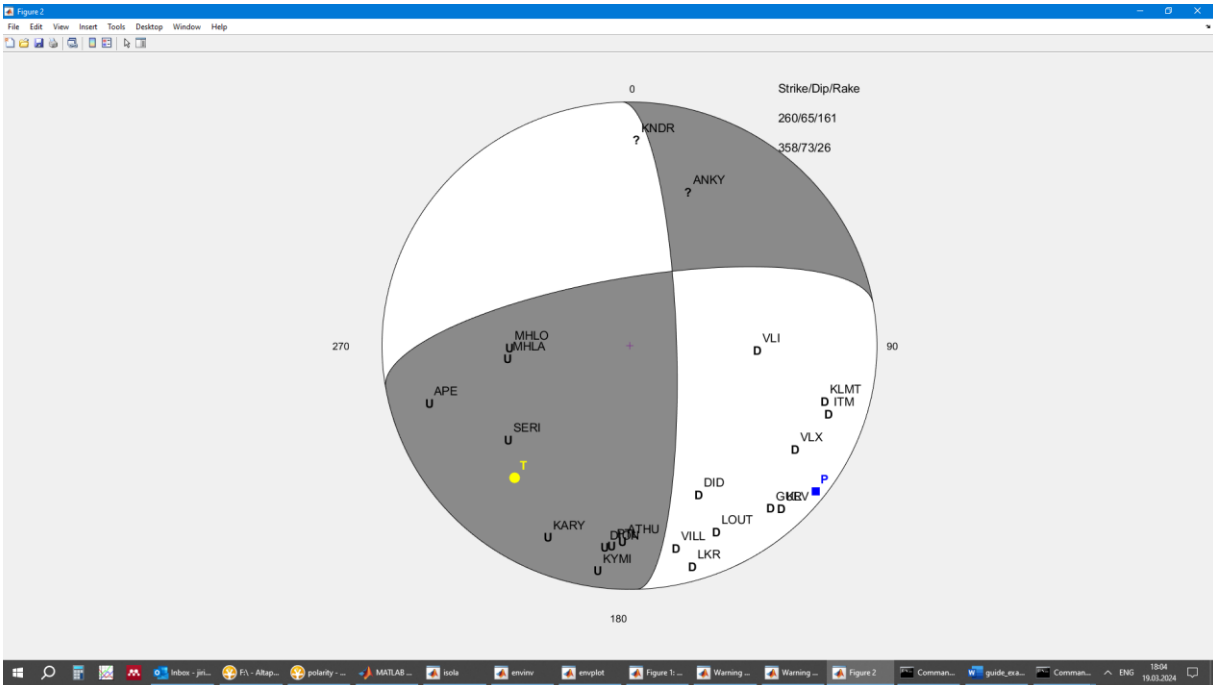
```
 >kagan_2solutionsonly

 READ REFERENCE strike1, dip1, rake1
260 65 161
 READ current  strike2, dip2, rake2
240 40 130
 rotangle=    34.6058088153876
```

Kagan angle of 34 degrees, representing the difference between the two mechanisms, is low. Indeed, Kagan below 40 degrees is often considered to indicate similar focal mechanisms.

Are the envelopes significantly different for s/d/r = 260/65/161? Make sdr.dat file with a line 260 65 161 and perform formal Polarity pre-constrained envelope ‘inversion’, in fact doing a forward simulation of envelopes. Do not mark the box Check polarity, Process, choose 1% and proceed to next screen, Plot the envelopes and plot polarities:





You find that when using the focal mechanism of the mainshock, we fit all the used polarities of the aftershock. Nevertheless, the fit of envelopes is worse with the mainshock mechanism.

We conclude that inversion of waveforms was not possible. Plausible inversion was obtained using envelopes, pre-constrained by many polarities. The earthquake had mechanism s/d/r= 240/40/130. This mechanism slightly differs from mainshock s/d/r = 260/65/161, with Kagan angle deviation of 35 degrees.