Regional moment tensor uncertainty due to mismodeling of the crust

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Abstract

The retrieval of earthquake moment tensor (MT) requires the response of the medium, in which seismic waves travel from the hypocenter to the stations, to be known. In inverting long-period (LP) seismic data (teleseismic and LP regional records), a gross earth model is sufficient; with decreasing periods, a more detailed model is needed. This is the case when waveforms of weak earthquakes at regional distances are to be inverted. Regional moment tensors (RMTs) of mostly Mediterranean earthquakes are determined on a routine basis by the Swiss Seismological Survey (SED) by using averaged models of the earth’s crust. By inverting broad-band records of the $M_w = 4.8$ earthquake near Udine, N Italy, on Feb. 14, 2002, we tested the sensitivity of the MT solution with respect to possible errors in the earth model used and in the location of the hypocenter depth. We perturbed the $P$ and $S$ velocities and the thickness in the 1-D earth model in the range from 3% to 30% of the parameter values and constructed estimates of confidence regions of the MT and error bars of the source time function (STF) and scalar moment in three frequency bands. Similarly, these error characteristics were determined assuming a mislocation in the hypocenter depth. We found that, in the band of periods from 25 to 50 s, the mechanism is resolved well (at the confidence level 95% at least) up to an earth model uncertainty of 30%, in the passband 10–25 s up to about 10%, but it is undetermined completely at periods of 5–10 s. An error in hypocenter depth of as much as double the value reported by the location procedure does not destroy the resolution of the mechanism at periods above 10 s. In the RMT catalog of the SED, earthquakes of $M_w$ greater than about 3.5 are processed at periods above 30 s; thus, the solutions for these events are robust with respect to a possible uncertainty in the earth model used. Mechanisms of weaker earthquakes, retrieved from short periods, should be interpreted with caution.

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Keywords: Mechanism of regional earthquakes; Perturbation of the 1-D earth model; Hypocenter depth mislocation; Confidence region of moment tensor

1. Introduction

Mechanisms of moderate earthquakes are precious data for studying the tectonics of active regions and their development in time. The coverage of active areas by seismic stations is usually sparse; thus, it is extremely important to determine reliably the earthquake mechanism from seismograms recorded at regional distances. This is not a trivial task, as regional waveforms may be rather complex, often difficult to decompose into individual seismic phases, and the available
models of the crust are usually rather simple. Retrieval of the mechanism requires the deconvolution of the response of the medium, through which seismic waves propagate from the hypocenter to the stations. The more complex waveforms (i.e., the higher frequencies) are to be matched, the smaller details of the earth structure should be included in the model of the crust. Teleseismic waveform inversions such as the CMT Harvard (e.g., Dziewonski et al., 2001) and USGS (e.g., Sipkin et al., 2002) solutions typically process waves of more than several tens of seconds, i.e., long enough in comparison with the space resolution of global seismic models. However, at regional distances, the records of weak earthquakes at periods of seconds and the first tens of seconds have to be inverted. Their wavelength may be comparable to the scale of the velocity models available. It is important to realize that regional models of the crust are only rough approximations of the earth structure across the area under study, usually ignoring features such as azimuth dependence of velocities, etc. It is then reasonable to test how the mechanism is biased when determined by using an inaccurate model in dependence on the frequency content of waves to be inverted.

Distortion of the mechanism due to inaccurate modeling of the earth has not yet been studied systematically. Moment tensors (MTs) of regional earthquakes are routinely determined by several groups: the Swiss Seismological Survey (SED) and National Institute for Geophysics and Volcanology (INGV) dealing with strong earthquakes throughout Europe with special emphasis on events from the Mediterranean (Braunmiller et al., 2002; Pondrelli et al., 2002, respectively), the Granada University dealing with earthquakes in the Ibero-Maghreb region of the Mediterranean (Stich et al., 2003), the National Research Institute for Earth Sciences and Disaster Prevention (NIED) in Japan (Kubo et al., 2002), and the University of California at Berkeley (Dreger, 2001). During the creation of the NIED catalog, Kubo et al. (2002) performed a simulation test by inverting synthetic waveforms constructed for a velocity model different from that used to construct Green’s functions (GFs). The change in the four-layer 1-D model was a shift of about 5 km in the depth of two-layer boundaries located above about 30 km. This resulted mostly in a change in the arrival time only (which must be compensated in inversion routines by default); the waveform shape was affected only little. Thus, the mechanism was changed negligibly. In compiling the regional moment tensor (RMT) catalog of the Mediterranean earthquakes, Braunmiller et al. (2002) tested several trial depths in the search for the best-fitting mechanism, and observed only a slight variation of the MT. Similarly, inversions performed with a different epicenter location for some events yield a slight MT change as long as the variation in epicenter distances and event-station azimuths remains small.

In a fast response to an earthquake, they determine a preliminary mechanism using the readily available records, and update it subsequently by exploiting more stations. They report that these mechanisms do not vary essentially, which may be regarded as an indication that the application of the averaged earth model is not crucial. Moreover, inversions at different but overlapping passbands provide similar solutions as long as the signal-to-noise ratio remains high in the passbands selected, and the synthetic and observed seismograms are reasonably in phase.

The purpose of this paper is to perform a more systematic study of the distortion of the mechanism due to inaccurate modeling of the earth’s crust. Since no estimates of error of the 1-D models used exclusively in regional studies are available, we performed a series of experiments simulating the uncertainty of the 1-D model of the crust ranging from a small one reaching the variation of the parameters of the model within 3% of their standard values to as much as 30% variation. We transformed the variation of the model into the confidence region of the fault plane solution (FPS), which allowed us to draw a conclusion about the stability of the determination of the orientation of the deviatoric part in the source. Another output is the confidence region of the non-double-couple parts of the mechanism. The characteristics mentioned will be determined in several passbands enabling a conclusion to be drawn about the stability of the FPS retrieved. The passband in the RMT catalog is related to the size of the earthquake; thus, we should be able to draw a conclusion about the threshold value of the magnitude, for which the FPS is still determined reliably, taking into account a realistic estimate of the uncertainty of the crust model. Similarly, we consider the mislocation of the hypocenter within the error reported by the
location routine and estimate the bias of the FPS retrieved in the selected passbands.

2. Data

To demonstrate the structure mismodeling/depth mislocation error, we selected one of the events from the SED RMT catalog—the $M_w = 4.8$ earthquake of Feb. 14, 2002, 3:18:01 near Udine in N Italy. This was a shallow intraplate event located at a depth of 12 km (USGS/NEIC Database, 2002). From the SED, we requested the BB records, which they applied in retrieving their RMT solution; at that moment (spring 2002), records were available from stations of the Austrian seismic network, the SED network and from MEDNET. From technical reasons, we exploited only the Austrian and Swiss stations (see Fig. 1 for the station distribution in azimuth and distance). Thanks to the limited passbands selected for the waveform inversion, the BB data proportional to the ground velocity (recorded by STS1 and STS2 seismometers) were multiplied by the gain of the instruments to obtain the ground velocity.

The SED RMT solution was obtained by inverting the ground displacement waveforms in the passband between 25 and 50 s. We inverted the ground velocity records in this passband and, moreover, in windows of 10–25 and 5–10 s to check how much the mismodeling and mislocation error in the resulting MT had increased. For the filtering we used the causal Butterworth band-pass filter of the third degree implemented in the Matlab 6 Signal Processing Toolbox. An example of the original velocity seismogram (station ARSA) and the filtered waveforms are displayed in Fig. 2; for the filtered waveforms, see also the bold lines in Fig. 3.

A simple 1-D model consisting of four layers over a homogeneous halfspace was used for the synthesis of GFs (Table 1). The GFs were constructed using the modified code AXITRA by O. Coutant based on the

Fig. 1. Location of the $M_w = 4.8$ earthquake of Feb. 14, 2002, 3:18:01 near Udine in N Italy, and stations used.

Fig. 2. Vertical velocity record at station ARSA (amplitudes in $\mu$m/s): (a) unfiltered signal; (b) signal filtered by passband between 5 and 10 s; (c) passband between 10 and 25 s; (d) passband between 25 and 50 s.
Fig. 3. Observed data (black lines) vs. synthetic seismograms (gray lines) at Austrian stations (left column) and Swiss stations (middle and right column) in the 25–50-s (a), 10–25-s (b) and 5–10-s (c) passband. Amplitudes in μm/s.
reflectivity and discrete wavenumber method (Cotton and Coutant, 1997; Coutant, 1994).

3. Method

To invert the waveforms, we used the INPAR algorithm (Šílený, 1998; Šílený et al., 1992) working with indirect parametrization of the source: the records are inverted into moment tensor rate functions (MTRFs) using the method of optimum filter design by Sipkin (1982) and, in the following step, the MTRFs are reduced to the MT and the source time function (STF). The unconstrained MT is decomposed into the double couple (DC), isotropic part (ISO) and compensated linear-vector dipole (CLVD). We are able to transform the error in the input data, i.e., the noise in the waveforms, into estimates of confidence regions of the MT and error bars of the STF. Assuming the error of the earth model and location of the hypocenter, however, is not as straightforward as the error of noise in the records. The correct approach is to include the conditional probability of forward modeling describing the uncertainty of the forward modeling into the formula for the probability density of the model parameters to be determined (Tarantola, 1987). Unfortunately, this characteristic is hardly ever available in practice. If any, only some estimates of the upper and lower limits of some of the parameters of the earth model may be at hand. More frequently, we are constrained only to foresee hopefully realistic estimates of the uncertainty of the parameters of the model in the form of a certain percentage of their

Table 1
1-D model of the crust consisting of four horizontal homogeneous layers overlying a halfspace

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth (km)</th>
<th>(v_P) (km/s)</th>
<th>(v_S) (km/s)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
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<tr>
<td>#1</td>
<td>4</td>
<td>2.25</td>
<td>3.09</td>
<td>2140</td>
</tr>
<tr>
<td>#2</td>
<td>1</td>
<td>5.5</td>
<td>3.09</td>
<td>2560</td>
</tr>
<tr>
<td>#3</td>
<td>6</td>
<td>6.6</td>
<td>3.7</td>
<td>2868</td>
</tr>
<tr>
<td>#4</td>
<td>22</td>
<td>7.1</td>
<td>3.98</td>
<td>3002</td>
</tr>
<tr>
<td>Halfspace</td>
<td>35</td>
<td>8.1</td>
<td>4.55</td>
<td>3290</td>
</tr>
</tbody>
</table>

Fig. 3 (continued).
current values. In addition, we must decide about the shape of their distribution within these limits, and we can then perturb randomly the values of the model parameters in accordance with the distribution. For the perturbed earth model, we compute Green’s function and, by using the difference of the synthetic seismograms, constructed for the perturbed and unperturbed (original) earth model, we estimate the error of the forward modeling converted into the data space (Šílený and Hofstetter, 2002). By repeating this procedure many times, we construct the distribution of the error due to mismodeling and pick up its representative characteristics, e.g., the most frequent value. This characteristic $\sigma_{\text{model}}$—the standard deviation due to mismodeling—should be added to the standard deviation due to noise in the records and can be transformed by INPAR into the error characteristic of the source. Similarly, we can estimate the error due to depth mislocation of the hypocenter by evaluating Green’s function in the upper and lower position set by the localization error, and compare the synthetics there with those in the hypocenter.

4. Results— inversion

The stations in Austria are closer to the epicenter of the event treated than those in Switzerland and their records thus have larger amplitudes. We do not perform distance weighting of individual stations in

Fig. 4. Source characteristics retrieved in the 25–50-, 10–25- and 5–10-s passbands. (a) MT in the traditional display of zones of compression (gray areas) and dilatation of first onsets; (bold lines) nodal lines of the DC part of the full MT; (triangles) T, N- and P-axes (principal axes of the MT). (b) MT in the display by Riedesel and Jordan (1989): (circle) descriptive vector (dv) of full MT; (square) dv of pure DC; (triangle down) dv of CLVD; (diamond) dv of ISO; (triangle up) T-axis; (triangle right) P-axis; (triangle left) N-axis; (dashed line) locus of deviatory solutions. (c) STF. Fault plane solution of the SED displayed for comparison.
the inversion; therefore, the least-squares procedure, matching preferentially large amplitudes, fits the records of the Austrian stations better than the records of the Swiss stations (Fig. 3). The fit at the most distant stations (Emv, Bour) is rather poor. Despite of this, our FPS in the 25–50-s passband, used by the SED to process this event, is close to the SED solution (Fig. 4). The SED FPS is nearly a vertical dip-slip striking NNE (dip 85, strike 217, slip −69), our FPS contains a larger strike-slip component (dip 85, strike 50, slip 42), but the vertical nodal plane strikes NE, i.e., similarly to the SED solution. Contrary to the SED MTs, which are obtained with the deviatoric constraint, our MTs are unconstrained, i.e., we invert for an isotropic component as well. Despite of this, we obtained nearly a pure DC (DC 93%, CLVD 5%, ISO 2%); see Fig. 4, part b for the 25–50-s passband. Another difference from the SED procedure is that we also invert for the STF. However, regardless of this difference in the method, our approach resulted in the same pattern—the retrieved STF consists of a single peak, which is the assumption in the SED approach. The STF and FPS retain this pattern also in the 10–25-s passband: in the STF, there remains a single peak and the FPS is even closer to the SED solution, comprising a smaller strike-slip component than in the 25–50-s passband (Fig. 4). However, there is much more of the non-DC components here—the CLVD amounts to as much as 50% of the mechanism. This is in agreement with the experience that a

Fig. 5. Modeling the distribution of $\sigma_{\text{model}}$, corresponding to the uncertainty of the velocity structure. We generated 100 perturbations of the 1-D model by perturbing randomly the depth of the interfaces and $v_P$ and $v_S$ velocities in four layers and the underlying halfspace. Random samples are taken from the Gaussian distribution with the standard deviation equal to 5% of the parameter value. For each model perturbation, the difference between the observed and the synthetic seismograms was evaluated and considered as a sample from the $\sigma_{\text{model}}$ distribution. The value corresponding to the maximum of the histogram was accepted (marked by the arrow) as the representative value for the construction of confidence regions of the source parameters.
mismodeling of the structure causes spurious source components to appear, because in short periods the mismatch between seismograms and synthetic signals constructed for a simplified earth model is more pronounced. The seismograms are modeled much worse here than in the 25–50-s passband, mostly the records of the Austrian stations being matched, but a large misfit occurring at the Swiss stations (Fig. 3b).

In the 5–10-s passband, the synthetic seismograms obviously are not able to model the observed records successfully (Fig. 3c). In the STF, there remains a single dominant peak, but the FPS is completely out of the pattern of the previous passbands (Fig. 4). Again, this agrees with the experience of the distortion of the MT retrieved with an inexact earth model— with a small mismodeling, spurious non-DC components appear while the orientation of the DC part remains stable, with a large mismodeling also the DC orientation is lost.

5. Results—error due to mismodeling

The main goal of our processing of the selected event parallel to the SED procedure was to estimate the error created by using a simple model of the crust, the parameters of which may possess some uncertainty. We have no information about the accuracy of the parameters of the 1-D model consisting of 4 homogeneous layers overlying a halfspace (Table 1). We thus assume that the errors are Gaussian, the standard deviation being a certain percentage of the value of the current parameter. To map the extent of the distortion of the mechanism in the passbands selected, we assume this percentage to range from 3% to 30%. In accordance with the Gauss distribution, the standard deviation corresponding to the selected percentage, we generated randomly the value of each parameter of the earth model and synthesized the corresponding Green’s function. The least-squares difference of the synthetics constructed for the origi-
nal and perturbed model, $\sigma_{\text{model}}$, form a distribution from which we pick the most frequent value as the error due to mismodeling, see Fig. 5 displaying the experiment with 5% model uncertainty and 100 perturbations of the model. The distributions of individual parameters are not always completely smooth, which indicates that more perturbations should be included, but the computation would then not be easily manageable.

Figs. 6–8 show the error of the retrieved source due to mismodeling amounting to 5%, which may be regarded as a low estimate of the uncertainty of the earth model. We estimated the error bars of the STF at several confidence levels (a), the error bars of the scalar moment $M_0$ from the shape of the posterior probability density (PPD) of $M_0$ (b); the confidence zone of the FPS—nodal lines of the DC part of the retrieved MT (c); and in (d) the confidence zones of the T-, N- and P-axes and of the vector MT in the Riedesel and Jordan (1989) formalism displaying uncertainty in the determination of the individual pure source mechanisms—DC, ISO and CLVD. In the 25–50-s passband (Fig. 6), the source is resolved very well: the single peak in the STF is significant at a high confidence level, the FPS is highly constrained (Fig. 6c, see also the small confidence zones of the T-, N- and P-axes in Fig. 6d), and the mechanism can be regarded as a pure DC (see the MT symbol in Fig. 6d coinciding with the symbol DC within the confidence region). The $M_0$ ranges from about $0.7 \times 10^{20}$ to about $2.5 \times 10^{20}$ Nm at the 95% confidence level (Fig. 6b).

Similarly, the resolution in the 10–25-s passband is also good (Fig. 7). In the STF, apart from the principal peak, there is another, but judging by the error bars it is not significant (Fig. 7a). The FPS remains highly constrained (Fig. 7c). A CLVD component amounting to 50% was determined in the mechanism (see the MT symbol shifted from the DC position towards the CLVD symbol in Fig. 7d). The MT confidence zone is larger than in the previous passband, but it is stretched perpendicularly to the locus of deviatoric solutions, which indicates some uncertainty in the DC vs. ISO resolution. The DC vs. CLVD resolution remains high—this means that the retrieved CLVD should be considered significant assuming the 5% uncertainty in the forward modeling. However, real-

Fig. 7. Inversion of waveforms filtered between 10 and 25 s. For details, see Fig. 6.
izing the tectonic setting of the Friuli area, the event processed is believed to be a DC and the CLVD detected in the 10–25-s passband is certainly an artifact of improper modeling of the crust. The fact that it was assigned as significant within the 5% error in modeling of the 1-D crustal structure indicates that this level of mismodeling may be too low.

The errors in the 5–10-s passband were found to be too high to determine any of the source characteristics reliably (Fig. 8). Regardless of the first peak in the STF having been detected as a dominant peak, it is insignificant even at the lowest confidence level considered (Fig. 8a). The FPS is completely undetermined (Fig. 8c), so is the content of the individual source components: despite the large ISO component (44%) observed here, its significance is low, thus the source can also be regarded as a pure DC (see the DC symbol inside the MT confidence region in Fig. 8d).

In order to estimate the upper limit for the uncertainty of the model of the crust, for which the FPS is still resolved successfully, we performed a series of experiments with the structure perturbation ranging

![Fig. 8. Inversion of waveforms filtered between 5 and 10 s. Estimates of confidence regions corresponding to the 5% uncertainty of the 1-D earth model. (a) Error bars of the STF; (b) PPD for scalar moment $M_0$ specifying its error bars; (c) confidence region of the nodal lines of the fault plane solution; (d) confidence region of the descriptive vector of full MT in the display following Riedesel and Jordan (1989); (e) confidence region of the T-axis; (f) confidence region of the N-axis; (g) confidence region of the P-axis.](image-url)
from 3% to 30% in the three passbands selected. Distributions of the $L_2$ norm of the differences between the synthetics corresponding to the original and perturbed earth model in the 15 experiments performed are displayed in Fig. 9. Due to the small number of perturbations, limited to keep the computations manageable, the distributions are not always smooth, but the trend of moving the most frequent values of the above differences upwards when increasing the error in the model and when decreasing the period of the inverted waveforms is obvious. In most cases, it is possible to select a value representing the maximum of the distribution, which we accept as the $\sigma_{\text{model}}$ — the error due to mismodeling converted to the data space. This quantity, however, does not always increase with the error percentage — see the

![Histograms showing the distribution of $\sigma_{\text{model}}$ for different periods and error percentages.](image)

Fig. 9. Distribution of $\sigma_{\text{model}}$, the difference of synthetic seismograms constructed for the perturbed and unperturbed model, in the 25–50-, 10–25- and 5–10-s passbands, and for the Gaussian error of the 1-D model parameters with the standard deviation ranging from 3% to 30% of the unperturbed value of each parameter. One hundred perturbations of the model were performed.
case of 20% and 30% in the 25–50-s passband, 3% and 5% in the 10–25-s passband, and 10–30% for 5–10 s. In these cases, the confidence regions are then the same.

The experiments testing the reliability of the FPS resolution in various passbands under simulated uncertainty of the earth model are summarized in Fig. 10. The FPS is determined well in both the 25–50- and 10–25-s passbands up to an error in the parameters of the 1-D model amounting to 10%: the confidence zones are tightly constrained still at the 99.5% probability level. Further increasing the mismodeling, in the 25–50-s passband, the 99.5% confidence zone expands largely and the FPS remains constrained at the 95% level, which may still be acceptable in practice. In the 10–25-s passband, the resolution drops to 90% and 70% for the model variation amounting to 20% and 30%, respectively.

Fig. 10. Confidence regions of the fault plane solution in the 25–50-, 10–25- and 5–10-s passbands due to mismodeling amounting from 3% to 30% of the values of the 1-D model parameters.
Thus, 20% may be regarded as the upper limit for the uncertainty of the model to obtain an acceptably constrained solution. In the 5–10-s passband, the FPS is completely undetermined even at the lowest level of the model uncertainty.

Starting at the 10% model uncertainty, the difference between the FPS retrieved in the 25–50- and 10–25-s passbands stays within the 99.5% confidence region, i.e., the FPS may be considered the same taking into account mismodeling of the crust. Below 10%, inversions in both passbands yield slightly different FPSs, their difference being significant. This indicates that the mismodeling of the crust may not be smaller than about 10%.

6. Results—error due to mislocation

We have tested two values of the depth mislocation of the event selected, 1.2 and 2.5 km. The former is the error reported by the location procedure, and we found it had only a small effect in the 25–50- and 10–25-s passbands: the FPS remained constrained very tightly at the highest confidence level tested (Fig. 11). On the contrary, in the 5–10-s passband, the nodal lines cover a compact zone at confidence levels less than 70% only, which is too low to be regarded as a reliable solution. This is in agreement with the FPS pattern itself, which is, in this case, very far from the solution obtained for longer periods, consistent with the SED solution. In addition, we explored the mislocation shifting the depth of the hypocenter by 2.5 km up and down. There is only a little difference as compared with the pattern of the small mislocation at periods of 10–50 s, but in the 5–10-s passband the FPS is totally undetermined even at the lowest confidence level. Thus, it seems that the standard mislocation does not essentially distort the FPS retrieval in the period range above 10 s.

7. Discussion and conclusions

At present, RMTs are being determined by several research groups for a wide range of earthquakes starting at $M_w$ of about 3.5 occurring within areas densely covered by seismic stations, up to the most severe events. The periods of radiated seismic waves differ largely, ranging from several seconds up to hundreds of seconds. For instance, in the RMT catalog of the SED, there are roughly 13 events (spring 2003) below $M_w = 3.3$ having occurred in Switzerland and its surroundings, which could have been processed thanks to the dense network of BB stations of the SED. To determine the source characteristics, the response of the medium in which seismic waves propagate to the stations (Green’s function) needs to be deconvolved from the records. However, usually only gross 1-D models of the crust, which are able to simulate only the long-period part of the

![Fig. 11. Confidence regions of the fault plane solution in the 25–50-, 10–25- and 5–10-s passbands due to mislocation of the hypocenter depth amounting to $\pm$ 1.2 km (the error reported by the localization procedure) and $\pm$ 2.5 km.](image-url)
observed records, are available. The parameters of these 1-D models should undoubtedly be regarded as averaged values subject to some uncertainty. Thus, it is reasonable to check how the retrieved source characteristics are biased due to this uncertainty, i.e., due to the mismodeling of the crust. The point may be crucial for weak earthquakes, where waveforms with prevailing periods of the first tens of seconds need to be processed. The windows for waveform inversion from events in the RMT catalog of the SED are displayed in Fig. 12. To check the effect of the mismodeling of the earth, we inverted the waveforms of the $M_w = 4.8$ earthquake of Friuli, N Italy in three passbands: 25–50 s, which is the range of periods used in the SED processing, 10–25 and 5–10 s. As no estimates of the error of the 1-D earth model are available, we considered a Gaussian error with the standard deviation amounting to 3–30% of the value of its parameters. The solution is the anticipated DC in the 25–50-s passband; for periods of 10–25 s, an additional CLVD appears and, in the 5–10-s passband, there is also an ISO component. The non-DC components detected below 25 s are obviously artifacts of the mismodeling of the crust; this effect was reported by, e.g., Kuge and Lay (1994), Šílený and Vavryčuk (2000) and Šílený et al. (2001). In practice, however, the non-shear part of the mechanism is not of prime interest, but the orientation of the DC component—the FPS is sought. The FPS appeared to be consistent with the SED solution at periods above 10 s. Taking into account the confidence region of the FPS describing its uncertainty due to crust mismodeling, the retrieved FPS is constrained tightly (at the 99.5% confidence level) up to the mismodeling amounting to 10%. At this percentage, the difference between the FPS in the 10–25- and 25–50-s passbands is not significant at the 99.5% confidence level. Above 25 s, the FPS is still resolved very well (at the 95% confidence level) even at the 30% uncertainty of the earth model. On the other hand, below 10 s, the FPS is completely undetermined even at the lowest confidence level tested (70%). It should be noted that our values are the lower estimates of the error due to mismodeling, as we stayed within the 1-D model common for all the stations in each perturbation, i.e., a variation of Green’s functions in azimuth was not simulated.

Browsing through the SED catalog, periods well above 30 s are processed for the RMT retrieval from earthquakes whose $M_w$ exceeds about 3.5 (Fig. 12). Thus, we can conclude that the FPS of the stronger earthquakes are not biased essentially by the mismodeling of the crust. On the contrary, there may be an uncertainty in the FPS determination of events below $M_w \approx 3.5$, if the mismodeling exceeds about 10%. The FPS may be totally undetermined from short periods below 10 s, but this range is used very rarely in the routine of RMT determination even for the weakest events processed (the only one in the SED 1999–2003 catalog).

Mislocations of the hypocenter depth not exceeding twice the error reported by the localization procedure do not hamper the FPS resolution essentially in the periods above about 10 s.

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References


