Assessment of Quality and Consistency of S-Wave Arrivals in Local Earthquake Data

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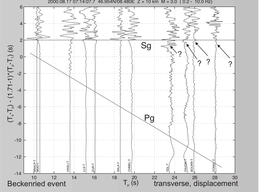
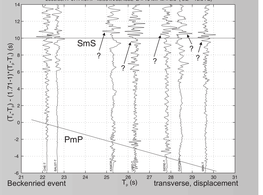
Overview

Structural models of the lithosphere based on P-wave velocities only lead to large ambiguities in terms of composition and physical parameters (e.g. fluid content, temperature). Additional information about S-wave velocities can put important constraints on composition and the physical state of the lithosphere, and improve the accuracy of the earthquake location. Since S-waves of local earthquakes are often contaminated by P-wave coda and S-P phase conversions, correct identification and timing of S-wave arrivals are difficult and sometimes ambiguous. To check the consistency of the picked S-wave arrivals obtained from the routine analysis of local earthquake data at the Swiss Seismological Service (SED) between 1999 and 2004, we apply the concept of minimum 1D models to P and S arrivals (independently and combined). In case of consistently picked S-waves we should observe only small deviations in hypocenters and residuals of relocated earthquakes between each model. Finally ,we compare the detected outliers with those derived from Wadati inversion, which is commonly used to assess the quality of S-arrivals.

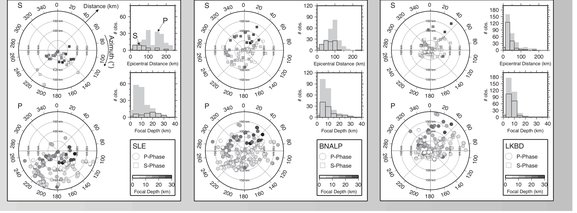
Introduction



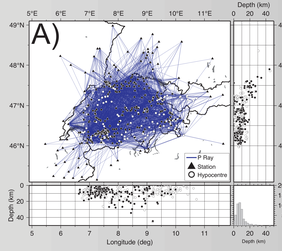


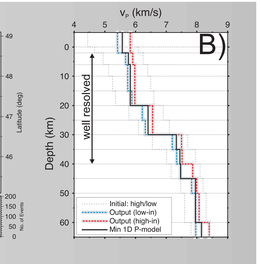
Example waveforms of the Beckenried earthquake illustrate the difficulties in phase identification and picking of local S-wave data. The seismograms are plotted as time reduced Wadati diagrams.

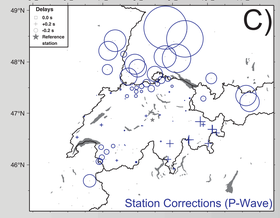
Stereographic diagrams for 3 Swiss stations demonstrate the distribution of azimuth, distance and focal depth for observed P and S arrivals. SLE shows prominent differences between P and S for larger epicentral distances.



Minimum 1D P





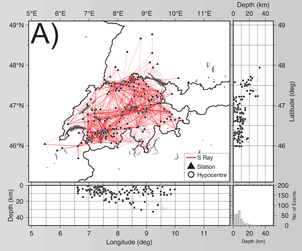


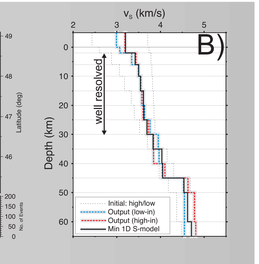
A) Selected data set to compute min. 1D P-wave model. Black dots: events common in P, S, P+S.
B) Minimum 1D P-wave model, and final models from "high-low" test.
C) Station corrections P-wave

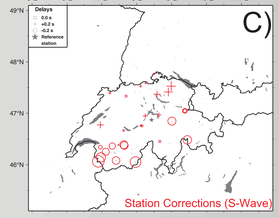
Statistics

Minimum 1D P					
# Earthquakes	470	Selection criteria: $N_P^{min} \geq 6$			
# Common events	238	GAP < 180°			
# Stations	173	Final RMS < 0.5 s			
Phase	Quality class	Obs. weight [%]	σ^{P} [s]	N^{obs}	Σ
P	0	100	± 0.05	4233	6317
	1	50	± 0.20	1861	
	3	13	> 0.20	223	

Minimum 1D S





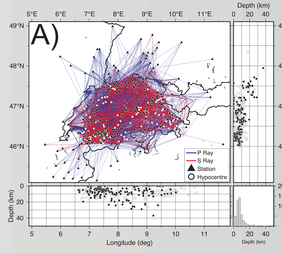


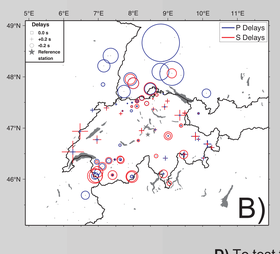
A) Selected data set to compute min. 1D S-wave model. Black dots: events common in P, S, P+S.
B) Minimum 1D S-wave model, and final models from "high-low" test.
C) Station corrections S-wave

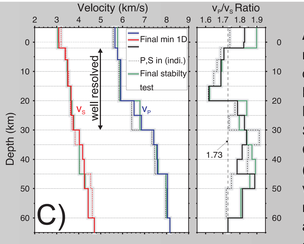
Statistics

Minimum 1D S					
# Earthquakes	296	Selection criteria: $N_S^{min} \geq 6$			
# Common events	238	GAP < 180°			
# Stations	108	Final RMS < 0.5 s			
Phase	Quality class	Obs. weight [%]	σ^{S} [s]	N^{obs}	Σ
S	0	100	± 0.05	1057	2330
	1	50	± 0.20	1235	
	3	13	> 0.20	38	

Minimum 1D P+S





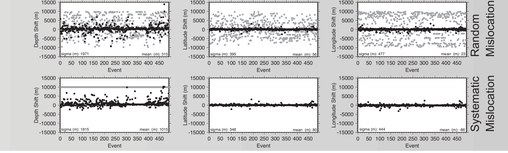


A) Selected data set to compute min. 1D P+S-wave model. Black dots: events common in P, S, P+S.
B) Station corrections for P- and S-waves.
C) Final minimum 1D model for P (blue, solid), S (red, solid) and vp/vs (black, solid). The initial models (independent models) are represented by the grey, dashed lines.

Statistics

Minimum 1D P+S					
# Earthquakes	492	Selection criteria: Events used for P and S			
# Common events	238	GAP < 180°			
# Stations	166	Final RMS < 0.5 s			
Phase	Quality class	Obs. weight [%]	σ^{P} [s]	N^{obs}	Σ
P	0	100	± 0.05	4039	6121
	1	50	± 0.20	1822	
	3	13	> 0.20	260	
S	0	100	± 0.05	1393	3153
	1	50	± 0.20	1686	
	3	13	> 0.20	74	

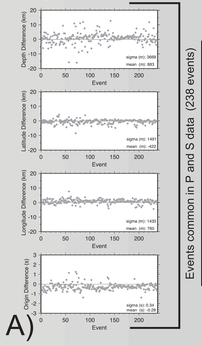
D) Stability Tests for Min. 1D P+S



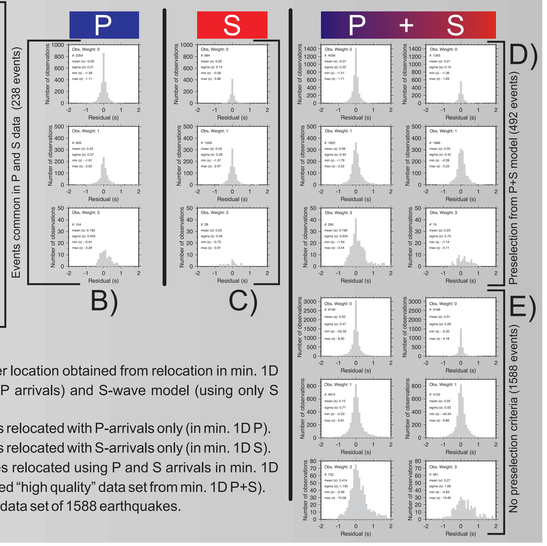
D) To test the robustness of the final minimum model, we shift the hypocenters randomly (lat,lon,depth) and systematically (depth) by 10 km before introducing them in the joint inversion (grey dots). Velocities are overdamped for test with systematically shifted hypocenters.
Hypocenters are relocated close to their original locations indicating a stable minimum (final hypocenters: black dots, final velocity model for random shift: solid green in **C**).

Hypocenters & Residuals

Hypocenters



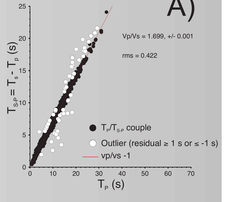
Residuals in Minimum 1D Models



A) Differences in hypocenter location obtained from relocation in min. 1D P-wave model (using only P arrivals) and S-wave model (using only S arrivals).
B) Residuals of earthquakes relocated with P-arrivals only (in min. 1D P).
C) Residuals of earthquakes relocated with S-arrivals only (in min. 1D S).
D) Residuals of earthquakes relocated using P and S arrivals in min. 1D P+S wave model (preselected "high quality" data set from min. 1D P+S).
E) Same as D) for unfiltered data set of 1588 earthquakes.

Wadati

Outliers:
Wadati:
56 (S-P)
Min. 1D P+S:
88 (P) + **37** (S)



A) Simultaneous Wadati inversion for the preselected P+S data set of 492 earthquakes. We define outliers (white dots) as residuals ≥ 1 s or ≤ -1 s.

Conclusions

We derive minimum 1D models for P, S, and P+S. Within these models hypocenters and residuals of the relocated earthquakes show similar results for P, S, and P+S. Mean values and σ of equal quality classes show no significant bias between P and S arrivals. Therefore we assume a comparable consistency of P and S arrivals in our data set. The amount of high-quality S arrivals is lower than for P. This can be explained by a higher conservatism in S arrival picking. In general we detect more and sometimes different outliers in the min. 1D model compared with the Wadati method. Since the later only detects T_S-T_P outliers, we can not distinguish between P or S mispick and have no information, if we observe only one of the two phases.

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