Automatic Seismic Phase Picking and Consistent Error Assessment: Application to Local Earthquake Data in the Alpine Region

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Introduction

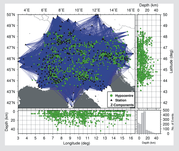
Inconsistencies in Merged Data Sets

Why Automated Repicking of Waveform Data?

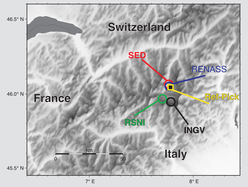
Data sets based on merged routine phase data from several networks usually include a significant degree of inconsistency due to:

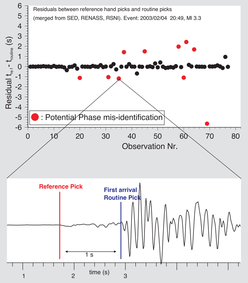
- Timing uncertainties of phase picks is often unknown or inconsistent.
- Phase identification is often not consistent. No consistent error assessment for merged phase data.
- Identification of common events can be biased through significantly different locations

Furthermore, modern data sets are usually too large for consistent manual repicking:



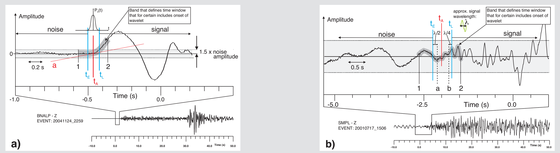
Waveform data set for Alpine region:
Networks: 13
Events: 1521
Stations: 381
Z-Comp: 72252
N-Comp: 35852
E-Comp: 35852





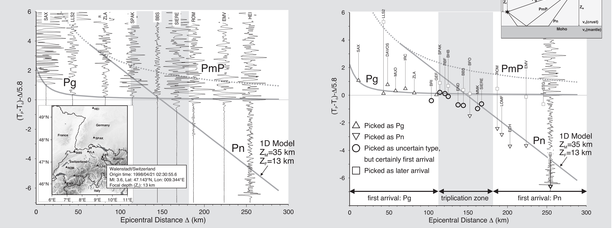
Consistent Quality Assessment

Consistent Timing Quality:



Probabilistic phase picking approach: the "earliest" possible pick corresponds to t_{el}, the "latest" possible pick corresponds to t_l. The most likely arrival time t_e is located within this interval. **a)** Primarily amplitude is used for determination of t_{el} and t_l. **b)** Primarily frequency is used for determination of t_{el} and t_l.

Consistent Phase Identification:



Automatic Picking System Mannekenpix (*MPX*)

Basic Concept

Wiener Filter
Used to determine threshold (picking engine), waveform charcteristics (predictors) for quality assessment, and waveform filtering

Picking Engine:
- Initial pick defines position of search window for repicking (**routine** pick if available or **predicted** from simple model)
- Extended Baer-Kradolfer (1987) algorithm

Quality Assessment Engine:
- True uncertainty class from discriminant waveform characteristics (predictors) via Fischer coefficients
- Weighting scheme has to be calibrated with a (hand picked) reference data set in order to adopt error assessment of seismologist: Multiple Discriminant Analysis (MDA) to find appropriate Fischer coefficients for data set

Consistently picked phases including individual quality assessment

1. Step: Calibration Procedure
=> **Reference Data Set:** consistent manually picked for representative subset of waveform data set
=> Adopt automatic picking and quality assessment to reference data

2. Step: Production Procedure
=> Initial picks necessary for all seismograms
=> Apply calibration scheme to complete waveform data set

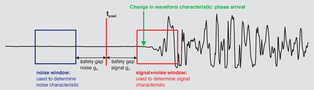
MPX Calibration Procedure

Summary of Picking Parameters to Calibrate:

MPX Parameter	Achieved by	Dependencies	Example from Alpine Ref. Data
Fischer coefficients (#Predictors x #Classes)	MDA, Test with Ref. Data	waveform characteristics of data set	not shown here
Length of analysing window (for Wiener Filter) (s)	Test with Ref. Data	dominant frequency content of signals	2 s
Set of safetey gaps for predicted pick (s)	Test with Ref. Data	scatter of predicted & frequency content	2.5 s, 1.25 s, 0.5 s, 0.08 s
Set of safetey gaps for routine pick (s)	Test with Ref. Data	scatter of routine & frequency content	not used
Lower frequency threshold (Hz) (Frequencies below threshold are not considered for SNR determination)	Test with Ref. Data	dominant signal frequency	0.50 Hz

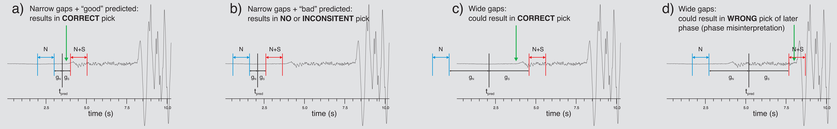
1. Step: Initial run of MPX to determine Fischer coefficients appropriate for specific waveform data set (Aldersons 2004)

2.Step: Adjustment of search window parameters

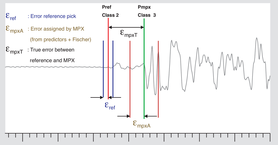


! Length of analysing windows (noise and signal+noise): Depending on signal frequency

! Safety gaps: Depending on scatter of initial pick and on signal frequency
Tradeoff between hit-rate and accurancy as illustrated in a) - d)



3. Step: Check of performance by comparison with reference data set

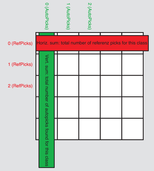


To assess the quality of the automatic pick we have to check:

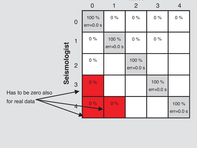
! **True error** ε_{mpxT} (difference between reference and automatic pick).

! **Difference in error classes** ε_{ref} **and** ε_{mpxA} (low quality reference picks should not be upgraded to highest quality class by MPX)

The Performance-Matrix: Smearing of quality classes and standard deviation "err" of ε_{mpxT} for each element



For ideal calibration:



Remark: This is an iterative process of repeating several times step 1-3 until satisfying result is achived

Application to Alpine Region

Reference Data Set

Error Assessment used for Reference Data Set:

Class	Error (s)	Weight
0	0.00 < |ε| ≤ 0.05	100 %
1	0.05 < |ε| ≤ 0.10	50 %
2	0.10 < |ε| ≤ 0.20	25 %
3	0.20 < |ε| ≤ 0.40	12 %
4	|ε| > 0.40	0 %

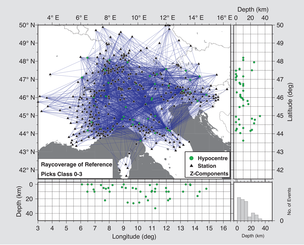
Phase label	Phase is…	Phase used for routine 1D arrival studies
Pg	Direct (crustal)	Yes (if first arrival)
Pn	Moho-refracted	Yes (if first arrival)
PmP	Moho-reflected	No
P1	Unknown type, but certainly first arrival	Yes
P2	Unknown type, second arrival	No
P3	Unknown type, third arrival	No
P	Unknown type, uncertain if first arrival	No

Picking Statistics for Reference Data Set:

Class	Number of Picks
0	773
1	926
2	905
3	502
4	901

Phase	Number of Picks
Pg	301
Pn	1959
P1	591
P	1156

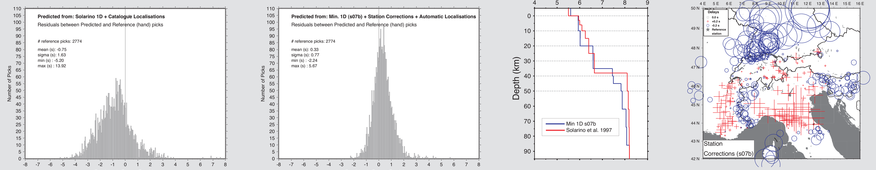
Number of Earthquakes: 43
Number of Stations: 359



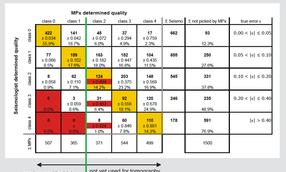
MPX Production Procedure

Initial Picks for MPX-Production Mode

The scatter of predicted arrivals derived from a standard model (Solarino et al. 1997 + catalogue locations) is too large to be used as initial picks (requires too wide safety gaps). The use of a min. 1D model (s07b) + station correction + relocated earthquakes (based on un-weighted automatic picks) leads to a significant reduction of the scatter and allows narrow safety gaps.



Performance of Calibration



Performance of Production

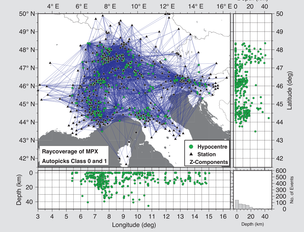
All events used for production: 916

MPX-DeterminedClass	MPX-Picks
0	6242
1	3207
Sum:	9449

Well locatable events with class 0 and 1 picks (Nobs > 5, GAP < 180): 407

MPX-DeterminedClass	MPX-Picks
0	4993
1	2595
Sum:	7588

consistent uncertainty: 0.00 < |ε| ≤ 0.100 s



Discussion & Outlook

The presented calibration and automated production procedure is able to pick the highest quality P-wave arrivals from a waveform data set of over 70,000 seismograms with an average uncertainty < 0.100 s. Such a performance cannot be reached in reasonable time by manual repicking. However, the present calibration downgrades too much of the "class 1" picks towards lower quality classes. In a next step, we will test an iterative calibration procedure (MDA for different subsets of data) in order to improve prediction and discrimination of class 1 and 2.

References

Aldersons, F. (2004) Toward a Three-Dimensional Crustal Structure of the Dead Sea region from Local Earthquake Tomography. *Ph.D. thesis*, Tel Aviv University, pp. 123.

Baer , M. & Kradolfer, U. (1987) An Automatic phase picker for local and teleseismic events. *Bull. seism. Soc. Am.*, **77**, 1437-1445.

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