Rapid Earthquake Association and Location

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Table of Contents

Seismic monitoring

Fast association of seismic phases and event location are crucial for real-time seismic monitoring.

Earthquake detection and location methods:

Usually divided into two main classes:

- Pick-based methods
  Three main sequential steps: (1) phase detection and picking, (2) phase association, and (3) event location.
- Waveform-based methods
  Detect, associate, and locate earthquakes simultaneously in a single step by maximizing the stacked waveform energy or coherence.

Pick-based or Waveform-based?

Waveform-based methods

- Are sensitive to weak signals and enable us to detect small earthquakes.
- Computationally expensive due to the need of an exhaustive search of potential locations in 3D space and potential origin times, sample by sample, in continuous data.

Pick-based methods

- Widely used in routine seismic monitoring due to their high-computational efficiency.
- The proper correlation of individual phases from the same source among different stations becomes difficult with multiple events close in space and time.

Table of Contents

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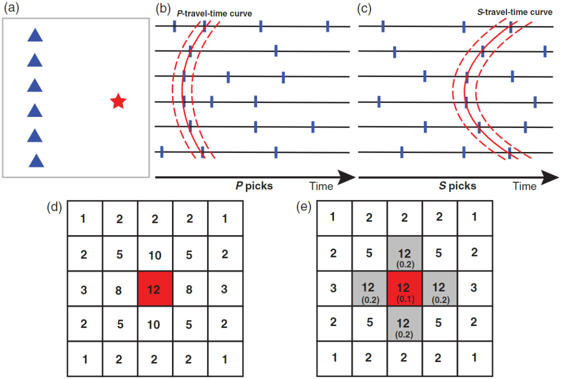

Figure: a) The distribution of seismic event and seismic stations. (b) P arrival-time curve (red curve) with its uncertainty range (red dashed curves) due to velocity uncertainty and limited searching interval, associated P picks and other false P picks. (d) The optimal location is determined to be at the grid point with most picks or (e) with smallest travel- time residual (in bottom parentheses, in seconds) and most picks if multiple locations have the same maximum number of picks.

- Count number of seismic picks.
- Calculate travel-time residuals.
- Dramatically reduces computation time due to very limited phase picks (far fewer than of continuous data samples).

Flow diagram of the REAL Algorithm

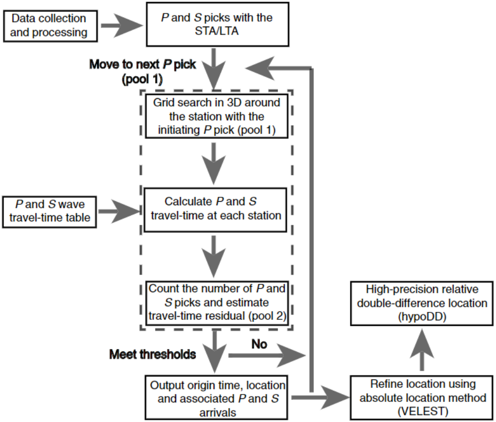

Figure: 2. Flow diagram of REAL.

- Step 1. *Phase triggering and amplitude estimation.*
  - STA/LTA (highest in 5s).
  - Estimation of amplitudes.
- Step 2. *Grid search and objective function calculation.*
- Step 3. *Criteria and feedback*

Table of Contents

Synthetic validation: 151 events, Central Apennines, Italy (14 Oct 2016)

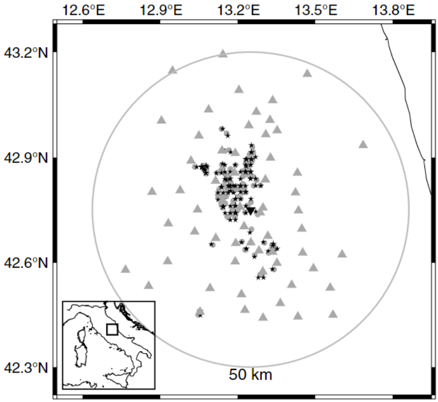

Figure: 3. Map showing seismic stations (triangles) within 50 km of the earthquake sequence, 151 Institute of Geophysics and Volcanology (INGV) cataloged events (gray dots), and their locations determined by REAL (black stars) in synthetic test.

- Simulated P and S picks calculating travel times for each event on the 60 stations.
- Mean location uncertainty: 0.74km in horizontal and 0.57 km in depth.
- Testing inaccurate velocity model using avg homogeneous P and S (6.2 and 3.3 km/s): 0.76 km (horizontal) and 0.57 (depth).
- Simulating inaccurate time picking (random perturbations between 0 and 0.4s)

Distribution of associated picks and travel time residuals.

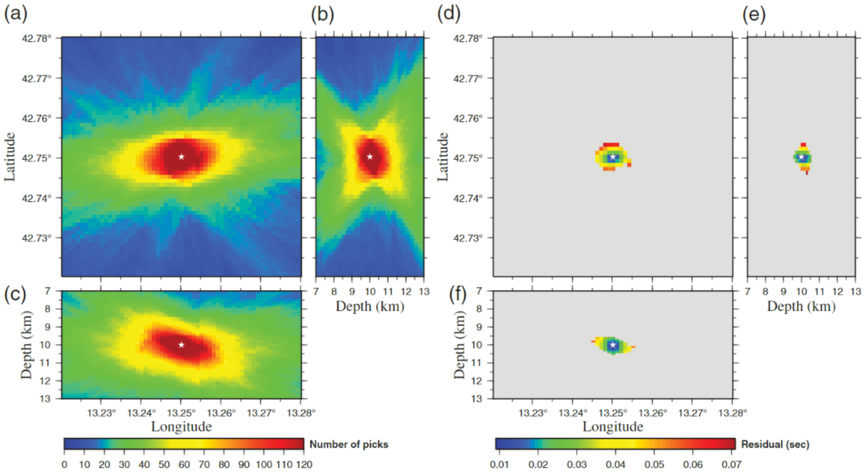

Figure: 4. (a) Distribution of number of P and S picks in longitude–latitude plane, (b) latitude-depth plane and (c) longitude-depth plane when applying REAL to associate and locate the synthetic event shown in Figure 3.(d–f) Distribution of travel-time residuals over the grids in (a–c) with the same maximum number of picks (120). White stars represent the optimal location determined by REAL.

Table of Contents

Application to 5 days continuous data in 2016 Central Apennines, Italy, Earthquake sequence.

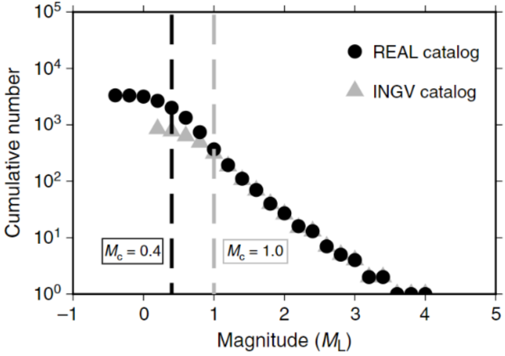

Figure: 5. Frequency–magnitude distribution and magnitude of completeness (M c) for the REAL and INGV monitoring room catalogs.

- REAL recovers all events M>1 (835) in INGV catalog.
- 26 small events M<1 were missed, for **three** possible reasons:
  - 1) Deficient seismic phase picking
  - 2) Their locations are close to the boundaries of the study area
  - 3) Occurred closely after other large events.
- Improvements in locations can be done with VELEST, and double-difference location method hypoDD.

Table of Contents

Conclusions

- REAL counts the associated seismic picks as objective function rather than enhance the energy or coherence of the seismic waveform.
- Compared to waveform based methods, REAL uses limited seismic picks rather than continuous data, reducing computational cost. Computational efficiency depends on number of seismic picks, search area, and grid spacing.
- Other seismic picking methods can be used in phase picking step to improve location precision.
- A disadvantage: it only keeps the most reliable event within a time window and can miss events that occur close in space and time.