2024 SCEC Internships: Discovering Hidden Earthquakes in the San Francisco Bay Area Using Template Matching

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Abstract

The increasing number of seismic sensors is leading to an ever greater data accumulation rate, making it difficult for seismic analysts to manually select and classify seismic events. In this study, we performed Template Matching to the San Francisco Bay Area, where a comprehensive earthquake catalog can improve the understanding of fault behavior and geometry. Accurately classifying seismic events can provide critical insight into the complexities of fault systems, which can then help anticipate earthquake hazards.

We compare continuous seismic data against templates from known seismic events to find previously undetected earthquakes. We selected 14 templates from known earthquakes in the vicinity of the Stanford campus, under the SLAC particle accelerator from 2020 to 2024. These templates are 5-second long vertical component seismograms. We scanned these templates on continuous data spanning the period 2010-2024 using EQcorrscan. Our analysis involved evaluating detection values, thresholds, and visual comparisons to assess the quality of waveform-template matches and confirm the reliability of detected events.

Template matching revealed *50 additional earthquakes, with magnitudes ranging from 0.06 to 1.3, that were not detected by the Northern California Earthquake Data Center (NCEDC) during the same period. In comparison, the NCEDC recorded 32 earthquakes in the same timeframe. Notably, the magnitudes of the template-matched detections were lower than those identified by the NCEDC, suggesting that template matching may be more sensitive to subtle signals that are often masked by noise. This capability highlights the potential of template matching to improve the sensitivity and resolution of seismic monitoring in the greater Bay Area.

The ability to identify additional seismic events highlights the importance of adopting advanced detection techniques to improve seismic hazard assessment, particularly in regions with complex fault systems.

* Updated from 63 to 50 earthquakes

Introduction

The rapid growth in seismic data collection challenges traditional manual analysis methods. In this study, we use Template Matching to enhance the earthquake catalog in the San Francisco Bay Area, aiming to improve our understanding of fault behavior and geometry. Accurate classification of seismic events is crucial for anticipating earthquake hazards.

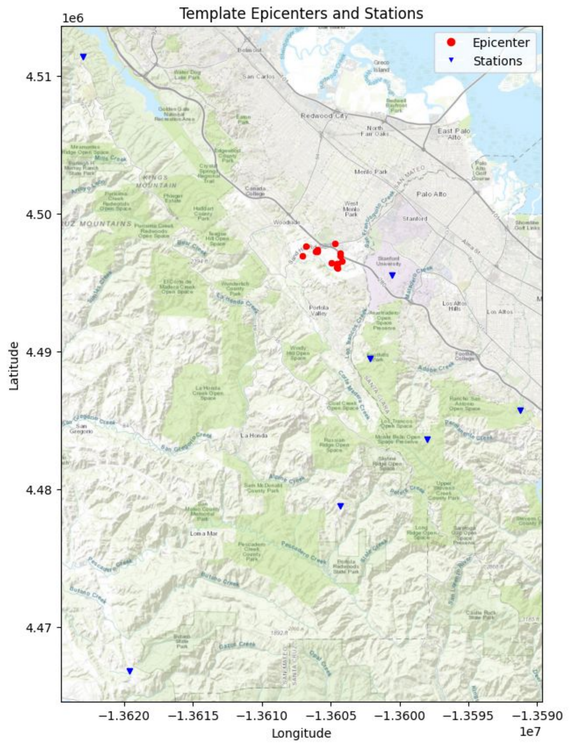
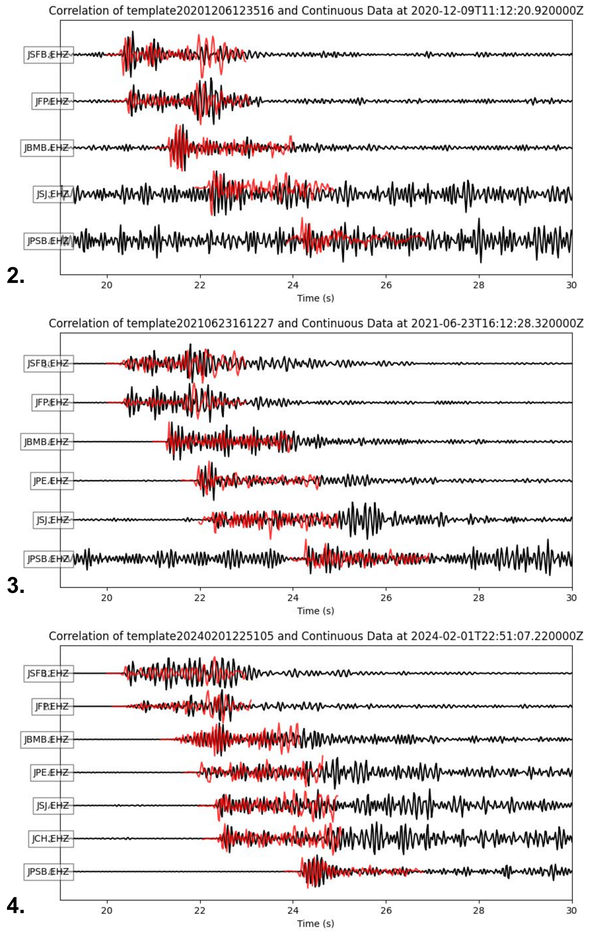


Figure 1: The map displays the epicenters of the templates used to search for earthquakes in the same vicinity, along with the stations involved in the cross-correlation analysis.

Methodology

We utilized 14 templates of earthquakes detected by the USGS near Stanford, under the SLAC particle accelerator, from 2020 to 2024. These 5-second vertical component seismograms were scanned against continuous data spanning 2010-2024 using EQcorrscan. We assessed detection values, thresholds, and waveform-template matches to confirm event reliability.



Figures 2-4: Examples of a detection record sections. Comparison of a template (red) aligned with continuous seismic data (black), demonstrating a potential earthquake by aligning the template with similar waveform patterns in the continuous data.

Results

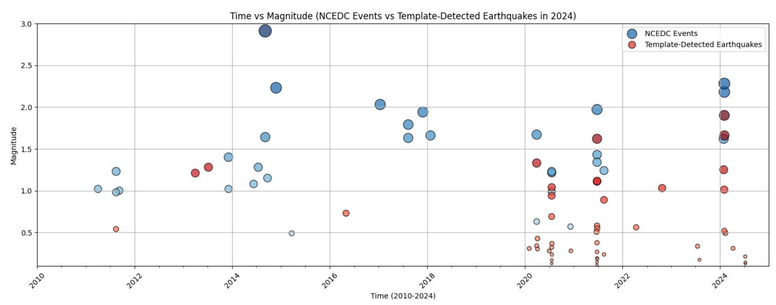


Figure 5: Scatter plot of earthquake magnitudes over time (2010-2024) for NCEDC and template-detected events. Template detected earthquakes on average had lower magnitudes compared to those recorded by the NCEDC.

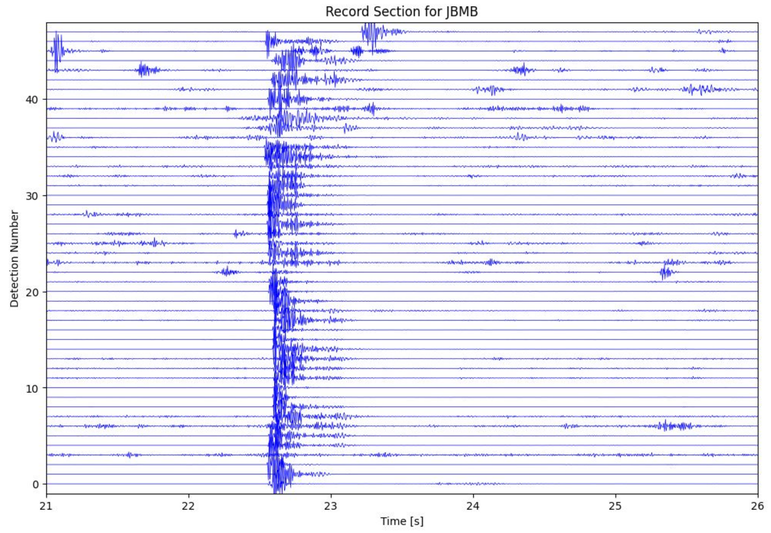


Figure 6: Plot of waveforms recorded by station JBMB for all detections. The aligned waveforms from multiple detections show consistent P and S wave arrivals and an absence of moveout, suggesting these events are equidistant from the station, consistent with repeating earthquakes or localized seismic activity.

Discussion

The discovery of additional seismic events using template matching emphasizes the need for advanced detection techniques to enhance seismic hazard assessment. Our results demonstrate that template matching is a useful tool for detecting previously unrecorded earthquakes in the Stanford area, particularly those of small magnitudes that may be missed by traditional automatic earthquake detection methods.

In comparing the alignment of the P and S wave arrivals across multiple detections at a single station, the lack of moveout suggests that these events may originate from a consistent location, possibly along the same fault segment.

Next steps would include accurately locating these detected events to better understand their spatial distribution and relationship to known fault structures in the area.

Applying this approach to the greater Bay Area could provide critical insights into the regional seismicity patterns, especially in understanding fault connectivity and behavior. A more detailed earthquake catalog containing smaller magnitude events is crucial to understanding subtle fault movements that may not be captured by larger events alone.

References

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