Using waveform correlation and template event metadata to reduce analyst workload

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INTRODUCTION

- Waveform cross correlation uses template waveforms from historical seismic events to detect recurring events from the same seismic source.
- Effective waveform cross correlation requires templates with broad frequency content to produce reliable single-station detections over a broad area, but because high-frequency information attenuates strongly over distance, such high-quality templates with broad frequency content only exist for stations at local to near-regional distances from the target seismic sources.
- Our research seeks to improve the effectiveness of waveform cross correlation detections through use of template event metadata and network analysis of corroborating stations.
- A network-focused perspective of recurring events improves the credibility of detections, since the number of stations that detected the template event originally, in combination with the relative amplitude of recurring detection, enables estimation of how many stations are likely to detect the subsequent event; thus, we select waveform correlation detections to reduce analyst workload.

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Example context: For a mining region in Wyoming with a high rate of repeating events, make high time-bandwidth long-duration templates from a close station (i.e., PDAR) with reliable signal detections.

Step 1: Correlate templates with incoming continuous waveform data from PDAR to detect possible new events.

Steps 2-6: Intelligently use expected information from other stations to corroborate so that resulting events are likely to be worthy of inclusion in an event bulletin.

1. Waveform Correlation Detector
2. Use template event metadata to find potential corroborating arrivals
3. Make templates based on Pn, Pg, Lg arrivals associated with the template event
4. Set template cross-correlation thresholds using time-reversed template method
5. Run correlations for time window around expected arrival time to detect corroborating arrivals for repeating event hypothesis
6. Do other templates detect corroborating arrivals consistent in time with repeating event?

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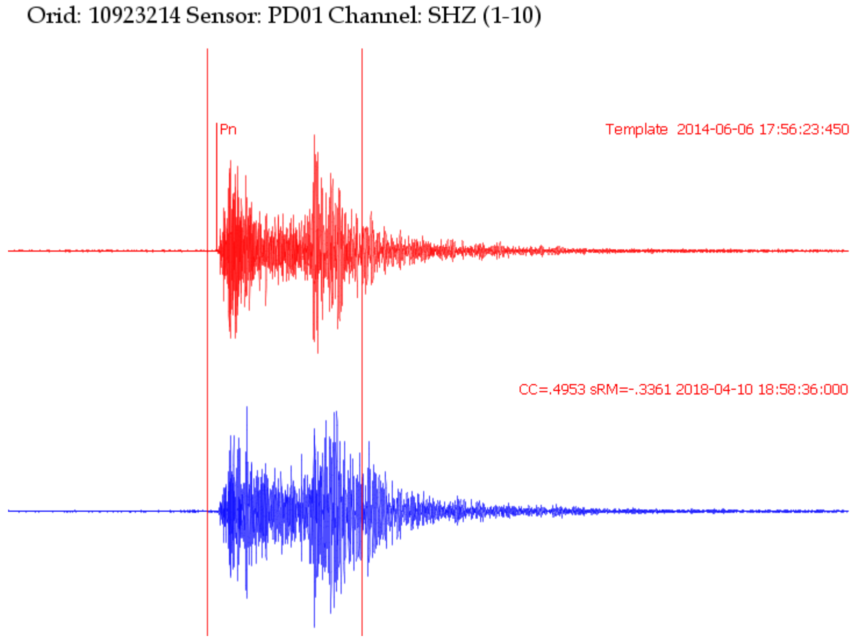
1. Waveform Correlation Detector

A template waveform from station PDAR detects an arrival.

The Pn/Pg template waveform is associated with **LEB ORID 10923214**



Template (Red) and Detection (Blue)

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2. Use template event metadata to find potential corroborating arrivals

Template Event:
LEB ORID 10923214

The template event recorded at a close station is used to compile the list of expected arrivals from a potential repeating event that would be recorded at other stations of the network.

STA	PHASE	Arrival Time (UTC)
PDAR	Pn	06-JUN-14 06.00.38 PM
PDAR	Pg	06-JUN-14 06.00.43 PM
ELK	Pn	06-JUN-14 06.01.43 PM
ULM	Pn	06-JUN-14 06.01.55 PM
ULM	Lg	06-JUN-14 06.04.26 PM
NVAR	Pn	06-JUN-14 06.02.27 PM
TXAR	Pn	06-JUN-14 06.03.18 PM
YKA	P	06-JUN-14 06.04.10 PM
TXAR	Pg	06-JUN-14 06.04.12 PM
ARCES	P	06-JUN-14 06.10.00 PM
FINES	P	06-JUN-14 06.10.43 PM
GERES	P	06-JUN-14 06.11.18 PM
AKASG	P	06-JUN-14 06.11.43 PM
ZALV	P	06-JUN-14 06.12.06 PM
SONM	P	06-JUN-14 06.12.18 PM
MKAR	P	06-JUN-14 06.12.42 PM

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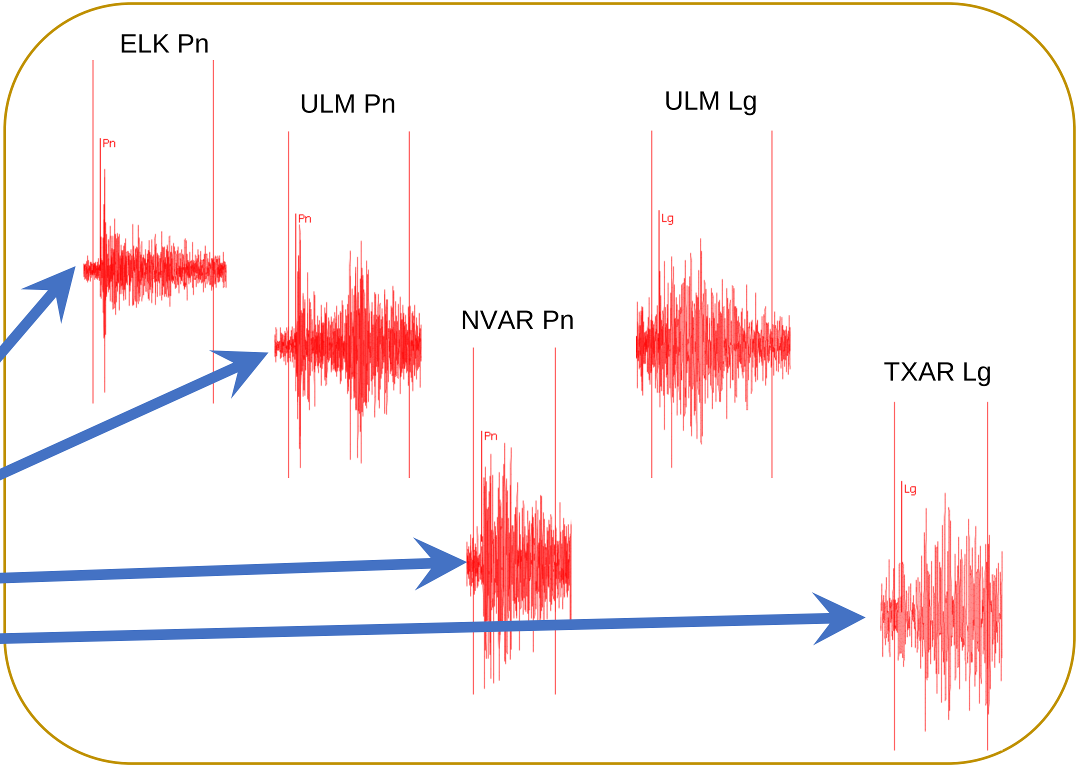
3. Make templates based on Pn, Pg, Lg arrivals associated with the template event

STA	PHASE	Arrival Time (UTC)
PDAR	Pn	06-JUN-14 06.00.38 PM
PDAR	Pg	06-JUN-14 06.00.43 PM
ELK	Pn	06-JUN-14 06.01.43 PM
ULM	Pn	06-JUN-14 06.01.55 PM
ULM	Lg	06-JUN-14 06.04.26 PM
NVAR	Pn	06-JUN-14 06.02.27 PM
TXAR	Pn	06-JUN-14 06.03.18 PM
TXAR	Pg	06-JUN-14 06.04.12 PM



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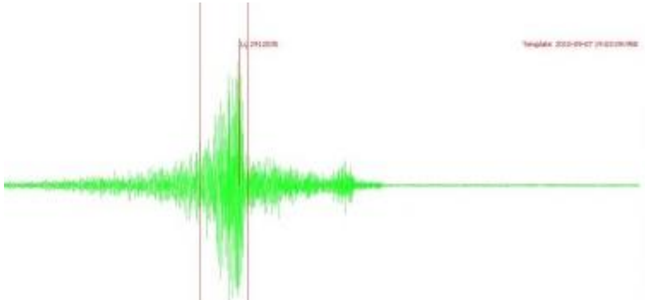
4. Set template cross-correlation thresholds using time-reversed template method[1]

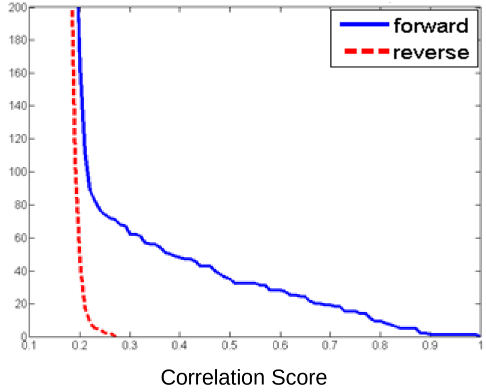
Example: time-reversed Lg template



1. Slinkard, M., D. Schaff, N. Mikhailova, S. Heck, C. Young, and P. G. Richards (2014). Multistation validation of waveform correlation techniques as applied to broad regional monitoring, *Bull. Seismol. Soc. Am.* **104**, 2768-2781. doi: 10.1785/0120140140.

The distribution of correlation values for a matched filter is theoretically the sum of 2 distributions: 1) correlation of the template with noise, and 2) correlation with similar events. We can obtain the false alarm rate for each correlation threshold from the distribution with noise. For the corroborating templates, the threshold was set to 1 false alarm per year (FAR = 1/yr).

Number of detections from forward and reverse templates



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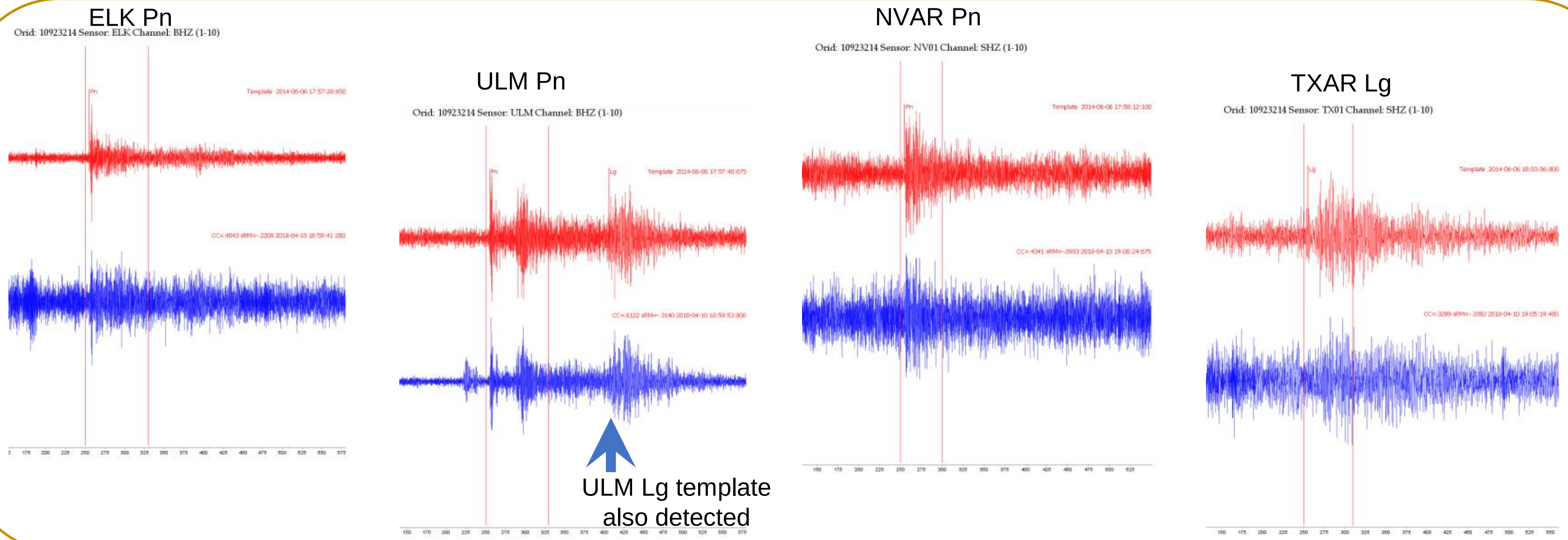
5. Run correlations for time window around expected arrival time to detect corroborating arrivals for repeating event hypothesis

Template (Red) and Detection (Blue) by Station



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6. Do other templates detect corroborating arrivals consistent in time with repeating event?

LEB ORID 10923214					
Station	Phase	Template date/time (UTC)	Detection date/time (UTC)	Template delta from PDAR (s)	Detection delta from PDAR (s)
PDAR	Pn	6/6/14 17:56:23	4/10/18 18:58:36	0	0
ELK	Pn	6/6/14 17:57:28	4/10/18 18:59:41	0.000752315	0.000752315
ULM	Pn	6/6/14 17:57:40	4/10/18 18:59:43	0.000891204	0.000775463
ULM	Lg	6/6/14 18:00:11	4/10/18 19:02:23	0.002638889	0.002627315
NVAR	Pn	6/6/14 17:58:12	4/10/18 19:00:24	0.001261574	0.00125
TXAR	Lg	6/6/14 18:03:06	4/10/18 19:05:19	0.004664352	0.004664352

DISCUSSION: Using waveform correlation only as a signal detector does not guarantee a reduction in analyst workload if marginal events that do not meet bulletin-inclusion criteria are detected. Our research targets the selection of waveform correlation detections that will lead to bulletin-worthy events. The chosen example shows that a credible repeating event can be detected by dynamically creating additional templates from arrivals that were associated to the template event. The individual waveform correlation detections may not be convincing (for example, view the detections for ELK Pn and NVAR Pn in Step 5), yet the combined group of corroborating arrivals are consistent in time with a repeating event. The table above shows that a simple calculation of time deltas can establish the credibility of the repeating event and can establish a relative location to the template event.

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FUTURE WORK

This research is in early stages, and the method will be applied to additional areas of high event rates of repeating events such as mining blast regions in Wyoming and Scandinavia and two aftershock sequences in the Middle East. At this time, only high time-bandwidth phases are used as templates (i.e., excludes teleseismic P templates). The research seeks to quantify parameters from the initial waveform correlation detection that favor the processing of templates for corroborating arrivals.

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