Sandia National Laboratories

SAND2019-14497C

National Nuclear Security Administration

Applying Waveform Correlation to Aftershock Sequences Using a Global Sparse Network[1]

Amy Sundermier*, Rigobert Tibi, and Christopher J. Young | *Sandia National Laboratories*

INTRODUCTION

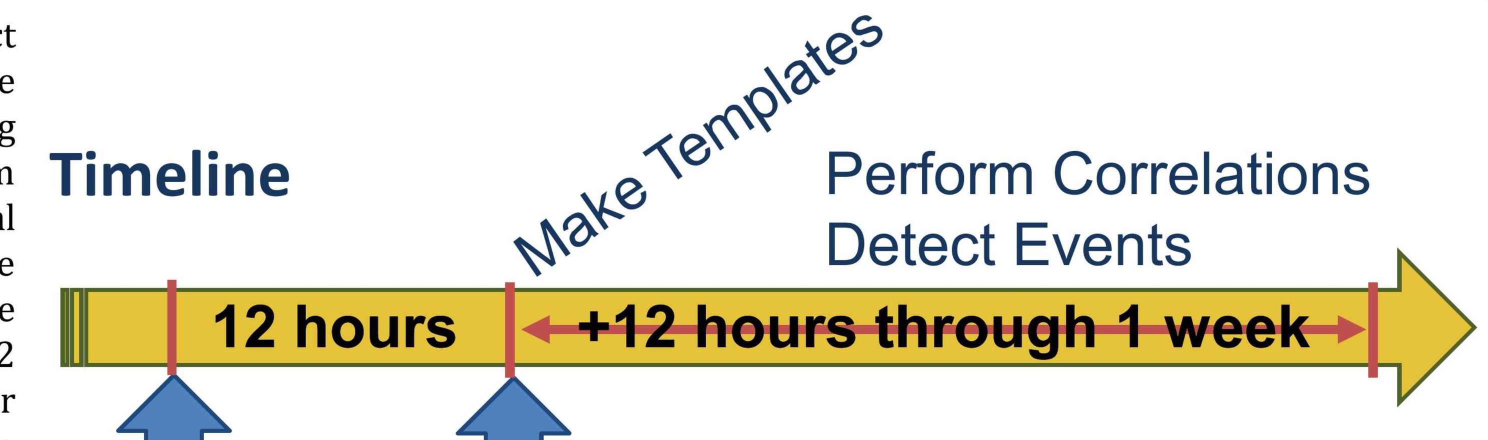
Studies have shown that waveform correlation is effective in detecting similar seismic waveforms from repeating earthquakes, including aftershock sequences. Monitoring agencies have shown interest in adopting techniques to quickly characterize aftershock sequences to reduce the amount of effort required by analysts to add aftershocks to event bulletins. Our experiment uses waveform templates recorded by multiple stations of the International Monitoring System (IMS) network during the first 12 hours after the main shock to detect and identify aftershocks that occur during the subsequent week. We present methods for station and template selection, threshold setting, and event detection that are specialized for aftershock processing for a sparse, global network. We apply the methods to several aftershock sequences to evaluate the potential for establishing a set of standard aftershock waveform correlation processing methods that can be effective for operational monitoring systems with a sparse network. We compare candidate events detected with our processing methods to the Reviewed Event Bulletin (REB), to develop an intuition about potential reduction in analyst workload.

EXPERIMENTAL SETUP

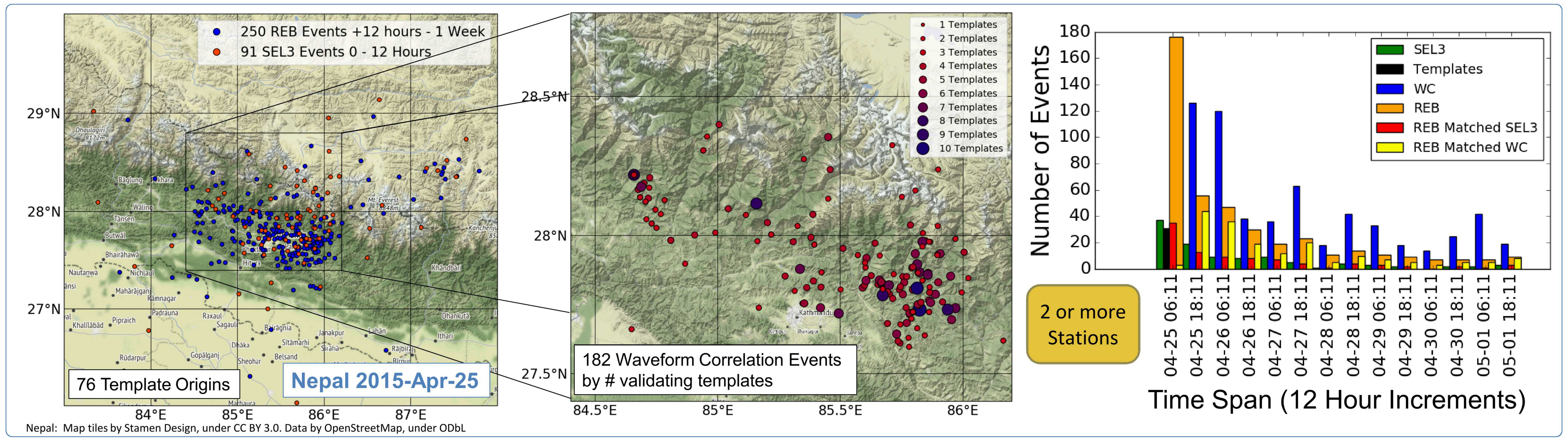
The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) chose four aftershock sequences and set the geographical footprint (see table below). The temporal span for all four sequences is [t_0, t_0+7days], where t_0 is the main shock origin time.

Sequence	Geographical footprint
Nepal 2015	±3° from [28.230°N, 84.731°E, 8.2 km depth]
Papua New Guinea 2018	±3° from [6.068°S, 142.768°E, 23.4 km depth]
Chile 2015	28°-34°S, 71°-75°W
Tohoku 2011	32°-44°N, 140°-146°E

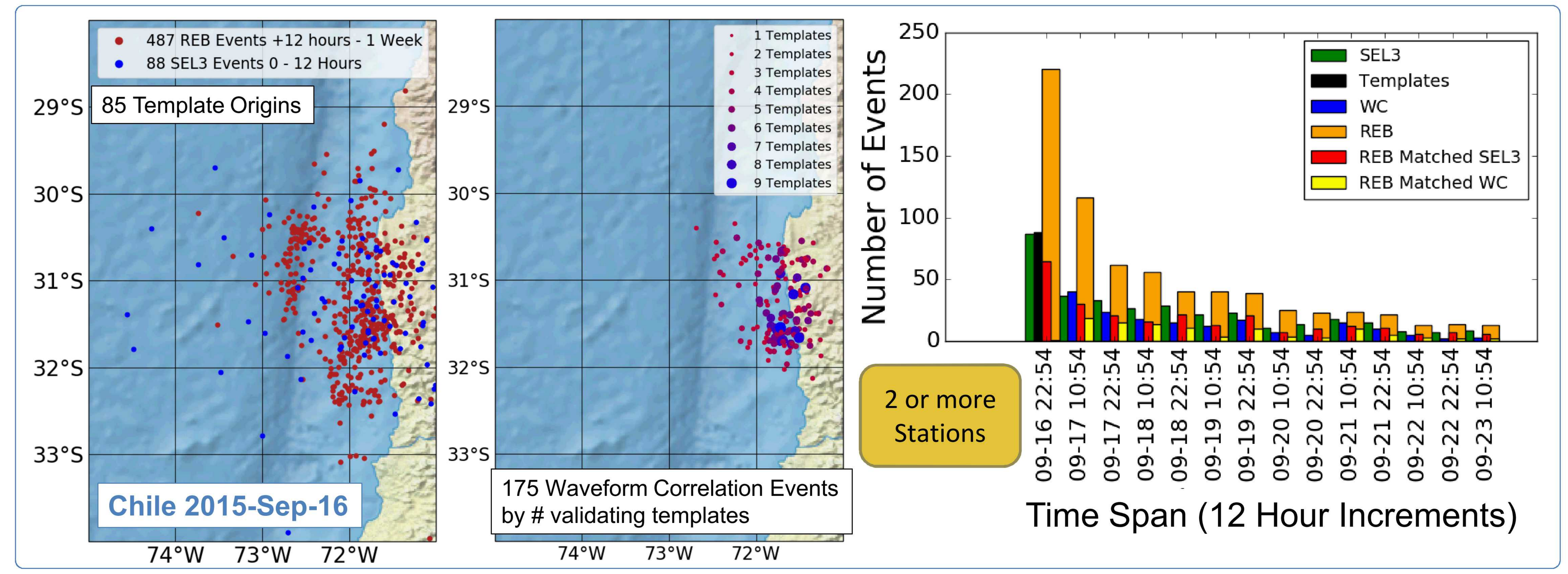
The goal of the research study is to detect and locate aftershocks within 1 week of the main shock with the overall aim of reducing analyst workload in monitoring system pipelines. The authors use Sandia National Laboratories' SeisCorr[2,3] to create template waveforms from International Data Centre (IDC) SEL3 events that occur within 12 hours after the main shock to detect later events. For this study, SeisCorr template waveforms are created only from prior events for consistency with operational real-time restrictions (see figure to the right).

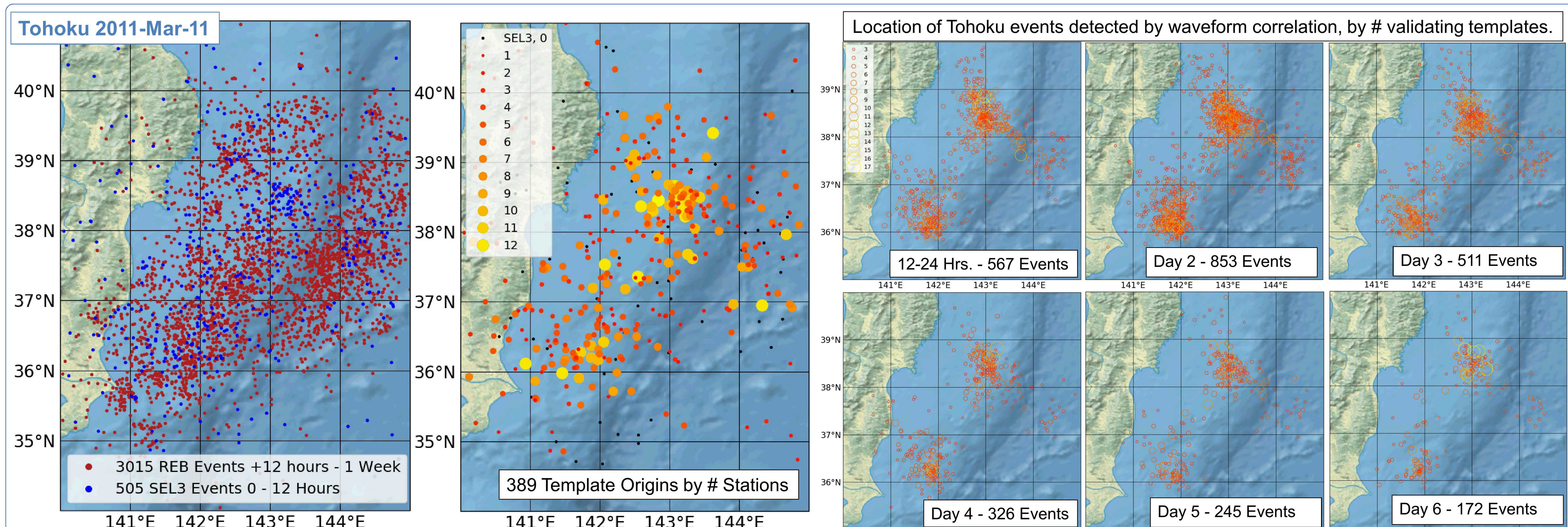


SEL3 – Standard Event List 3 is generated by the IDC automated pipeline and includes detections from both primary and secondary stations along with calculated locations. SEL3 is not an analyst-reviewed event list.

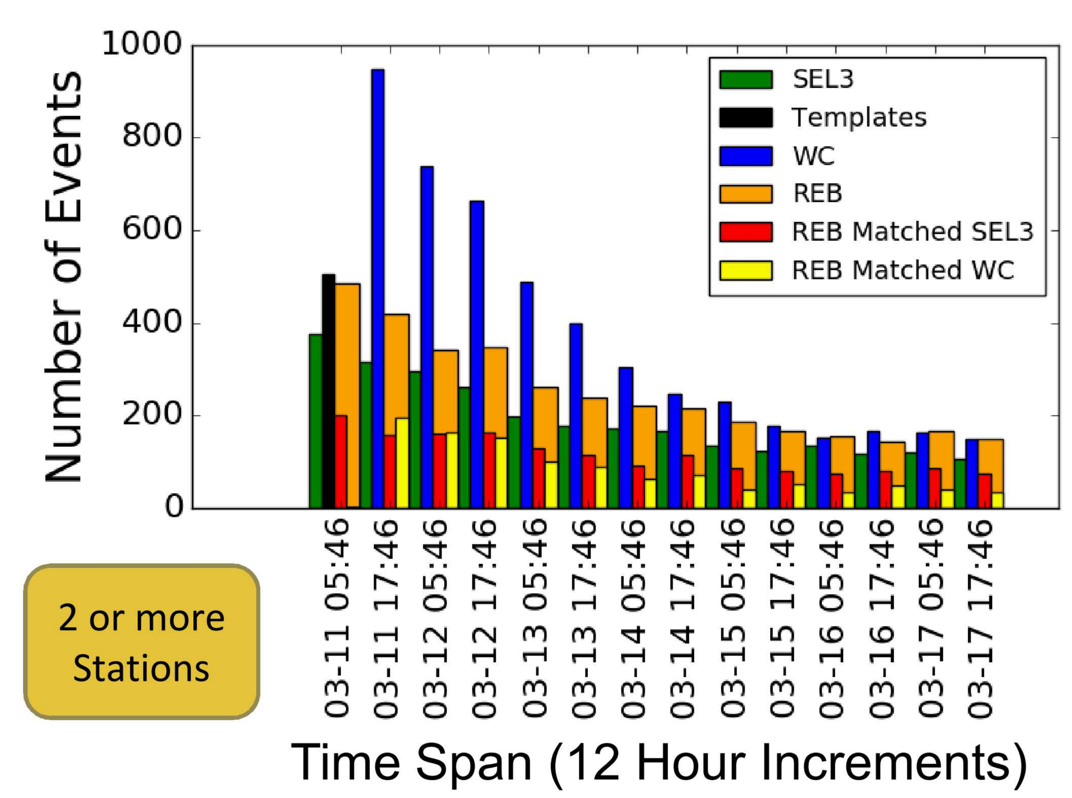


Nepal: Map tiles by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under ODbL

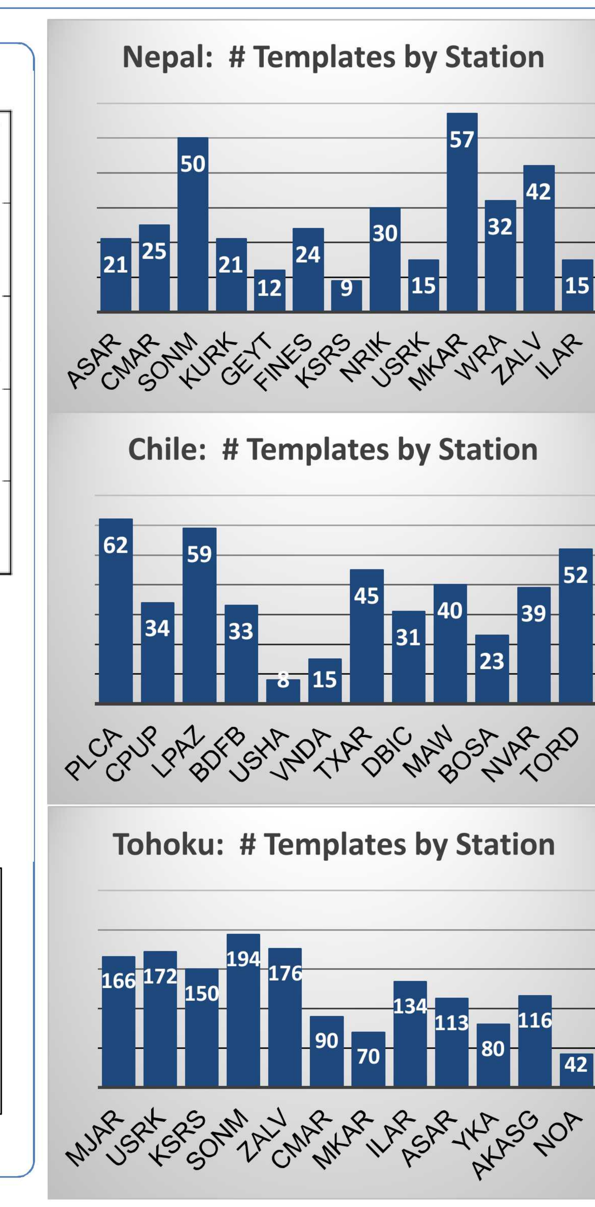


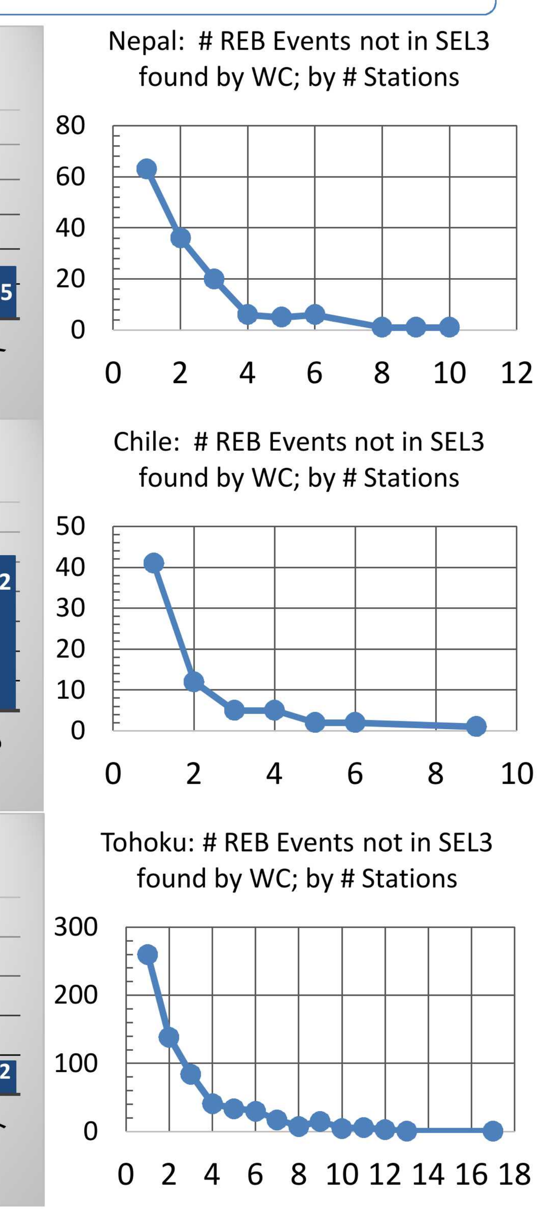


Tohoku and Chile maps: Made with Natural Earth.



Waveform correlation (WC) (blue) versus SEL3 (green) and REB (orange) events, REB events that matched SEL3 (red) and waveform correlation (yellow) events within 1.0° and ±15s. The graph shows events for 2 or more stations for 12 hour time periods.





DISCUSSION

Goals of this study include 1) investigating whether implementation of waveform correlation techniques to process aftershock sequences may reduce the human analyst workload required to produce an event bulletin during periods of high aftershock event activity, 2) developing a method within the constraints of an operational system (e.g., no templates from future events), and 3) using real event data from the IMS network to quantitatively estimate potential benefits of the method. The templates were based on first P arrivals in the SEL3 catalog, with a 15 second window to reduce the potential for overlapping events. The authors chose to make template libraries for stations that had a large number of arrivals from the study region during the first 12 hours of the aftershock, and preferred stations that were geographically close to the study region. Preliminary investigation indicated that processing continuous data from at least 12 stations was necessary to validate detections with multiple stations (i.e., templates) for the example sequences. The study results are encouraging because waveform correlation detected events within a tolerance of 1 degree and ±15 seconds that were not in the automatic SEL3 catalog, but were later added by human analysts to the REB catalog. The table to the right shows a simple quantitative estimate of the potential reduction of analyst workload based on added REB events, since augmenting the automatic catalog is time-consuming for the analysts.

Future research may include exploring additional aftershock sequences, such as the Papua New Guinea 2018 earthquake, to investigate the generality of the method employed in this study. The authors also want to investigate methods to use single station waveform correlation detections of aftershock events without burdening the analyst with more events to review.

RESULTS

Estimated workload reduction for analyst-built events = $\frac{(\#\ REB\ events\ matching\ WC\ not\ in\ SEL3)}{(\#\ REB\ Events - \#\ REB\ Events\ matching\ SEL3)}$

Sequence	# WC events (ndef ≥ 2)	# WC events (ndef ≥ 1)	# REB events	# REB events matching SEL3	# WC events matching REB	# REB events matching WC not in SEL3	Estimated Workload Reduction
Nepal 2015	182	597	250	57	179	127	**72%**
Chile 2015	175	589	487	182	175	61	**22%**
Tohoku 2011	4840	11033	3015	1415	1494	624	**39%**

REFERENCES

1. Sundermier, A., R. Tibi, and C. J. Young (2019). Applying Waveform Correlation to Aftershock Sequences using a Global Sparse Network, Technical Report SAND2019-10184.
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3. 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.

*** asunder@sandia.gov** // **Ground-Based Nuclear Explosion Monitoring Research and Development**