

Using waveform correlation to reduce analyst workload during aftershock sequences



Amy Sundermier, Rigobert Tibi, Christopher J. Young

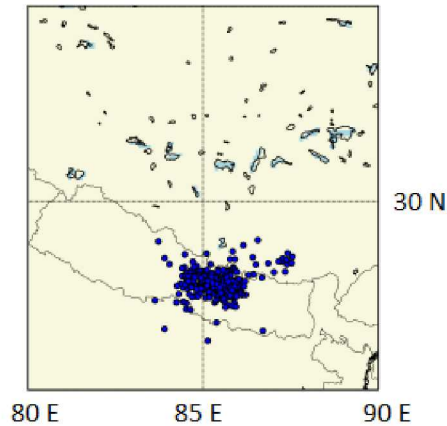


Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

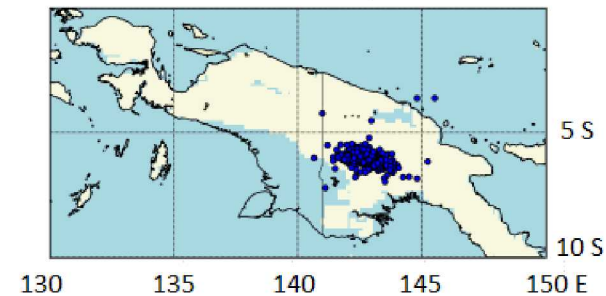
Provisional Technical Secretariat (PTS) Initiated Study of Waveform Correlation Techniques to Detect 2 Types of Recurring Events

Aftershocks

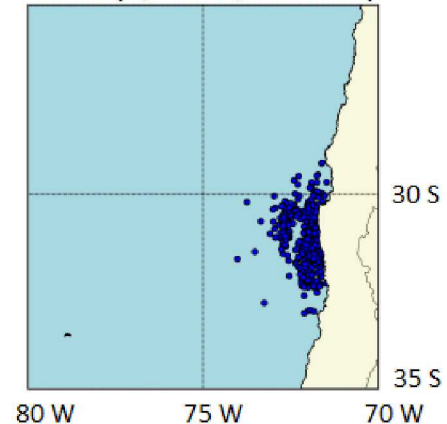
Nepal (4/2015, 7.8 Mw)



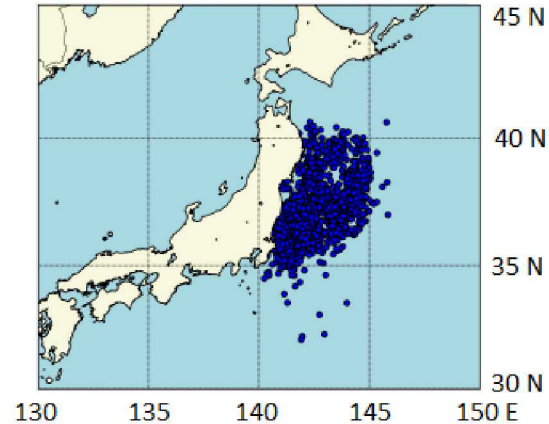
Papua New Guinea (2/2018, 7.5 Mw)



Chile (9/2015, 8.3 Mw)

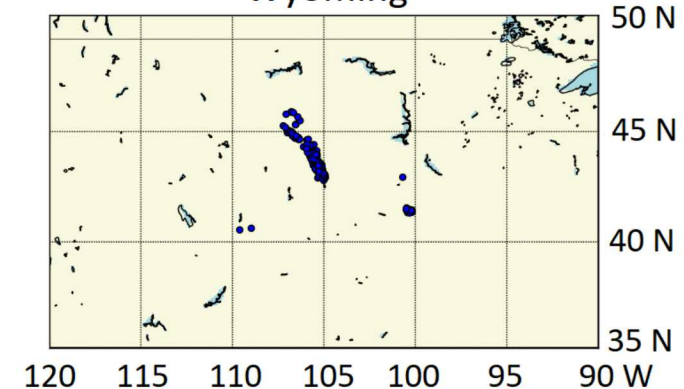


Tohoku (3/2011, 9.0-9.1 Mw)

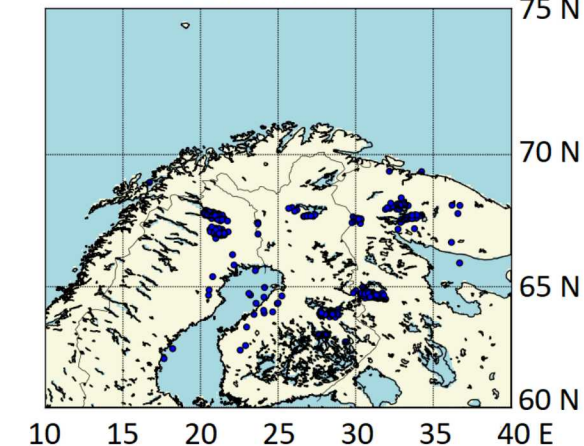


Mining Blasts

Wyoming



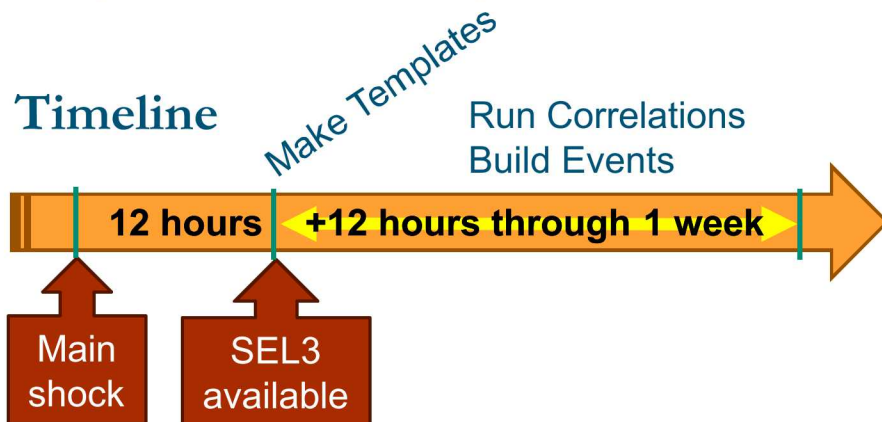
Scandinavia



Aftershock Study

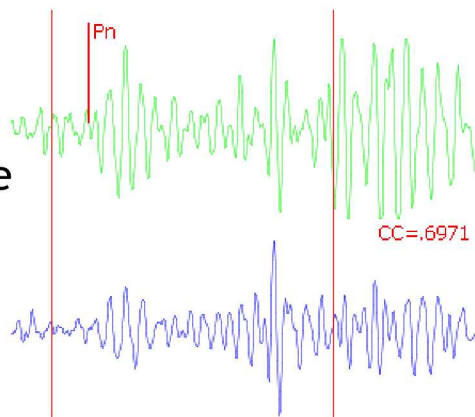
Waveform correlation uses waveform templates to detect subsequent events.

Experimental Setup

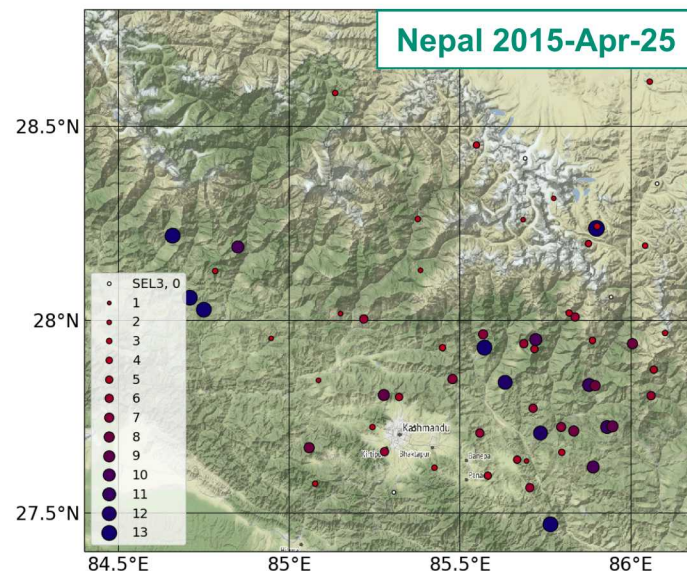


Example Template
CMAR, 15 s, Pn phase

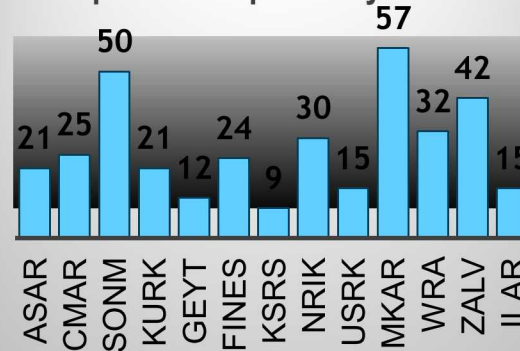
Detection
CC score = 0.6971



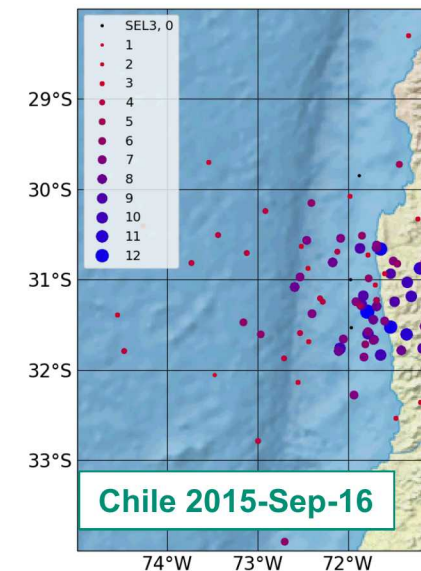
Nepal: 76 Template Events



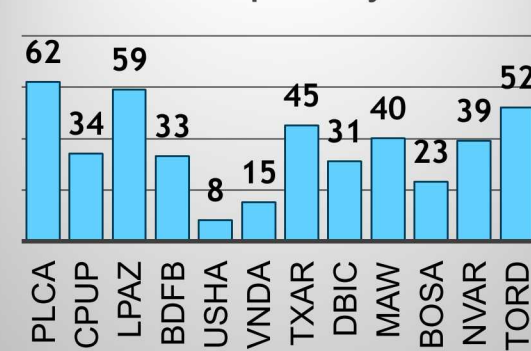
Nepal: # Templates by Station



Chile: 85 Template Events

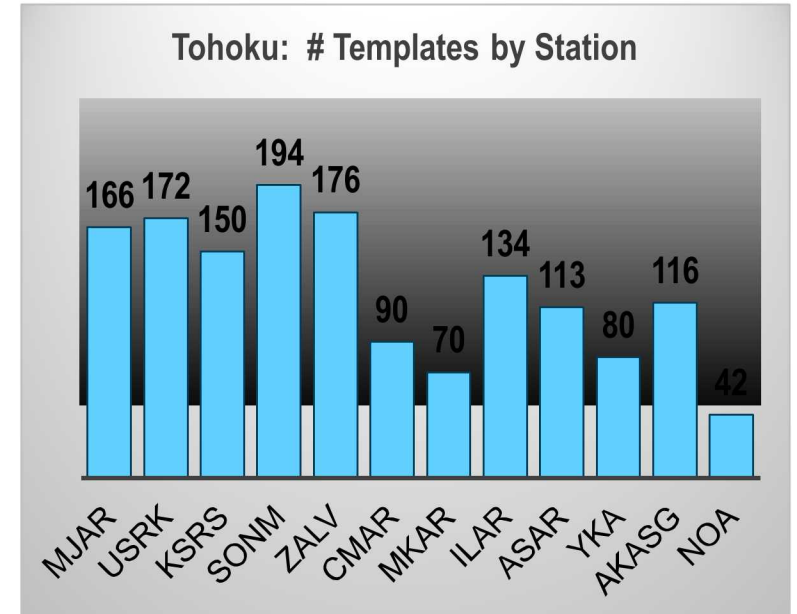
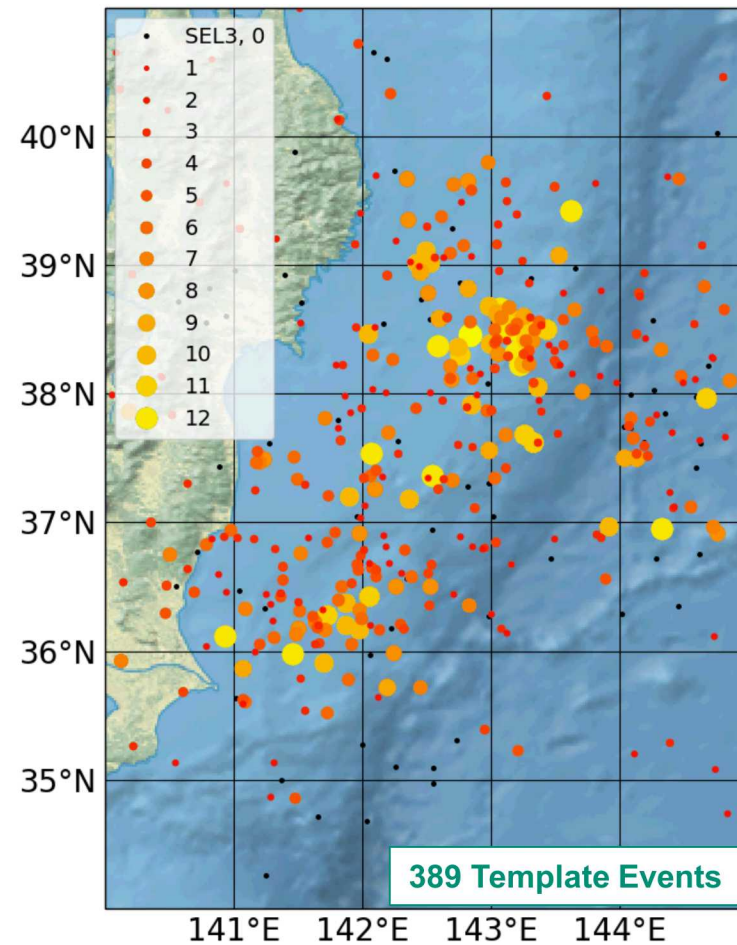
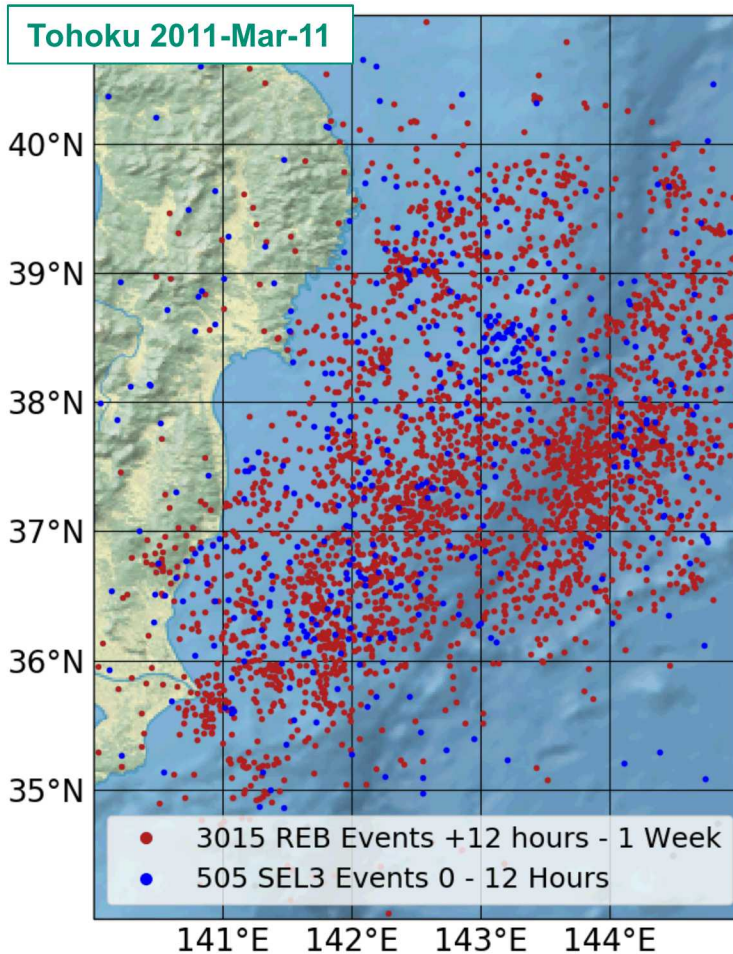


Chile: # Templates by Station



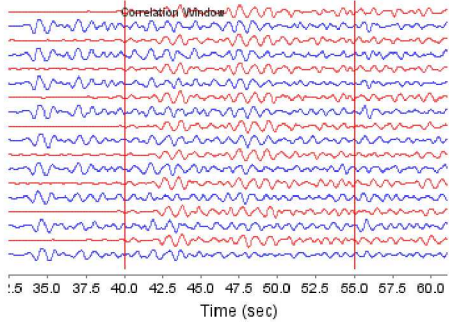
Example: Tohoku 2011-March-11

SEL3 Catalog event arrivals are turned into waveform templates.

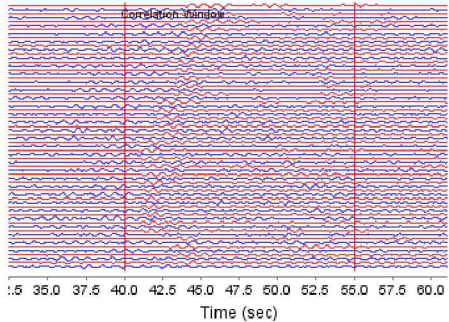


Tohoku 2011 – Correlation, Detection, Multistation Validation

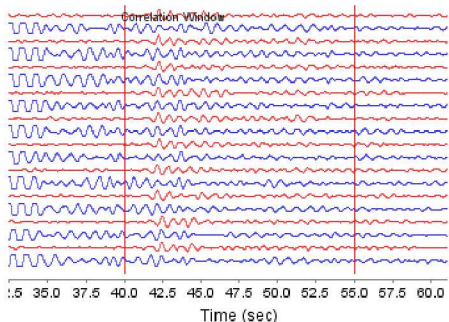
MK01 Orid: 7222635 Score: .596



NAO00 Orid: 7219976 Score: .248



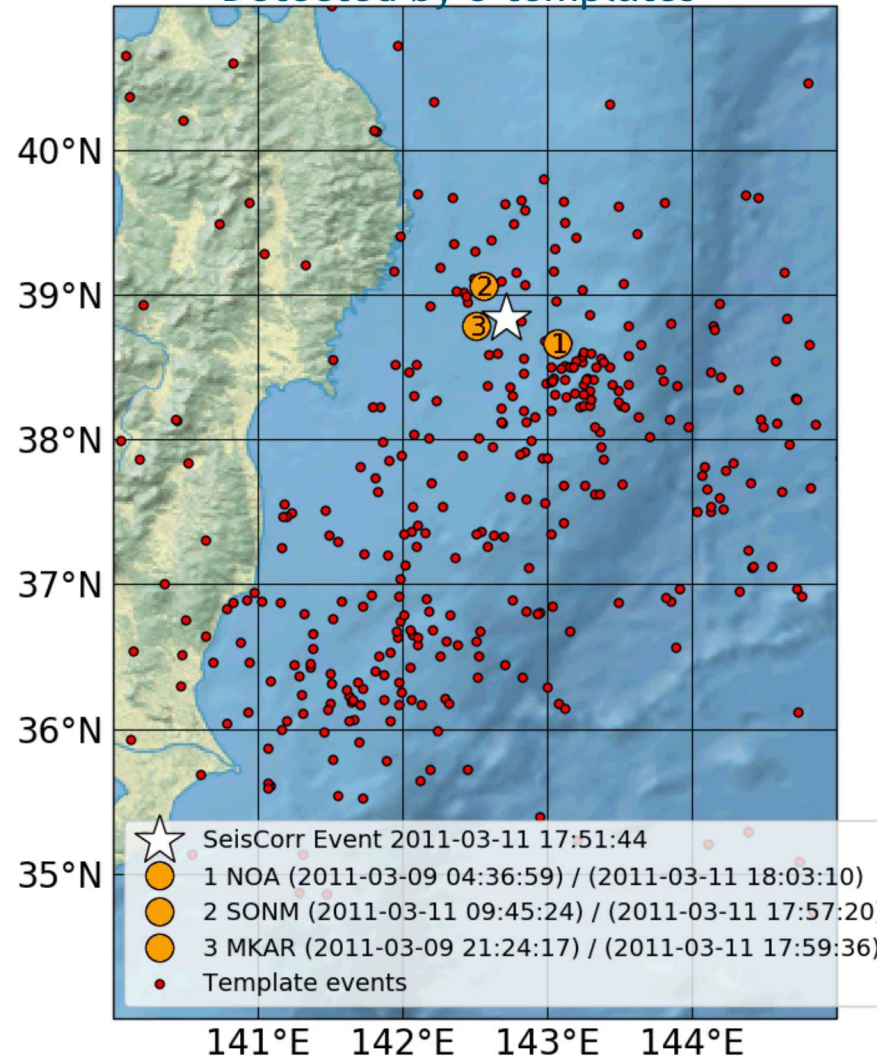
SONA0 Orid: 7268848 Score: .542



SeisCorr Event 24972925

Example Event

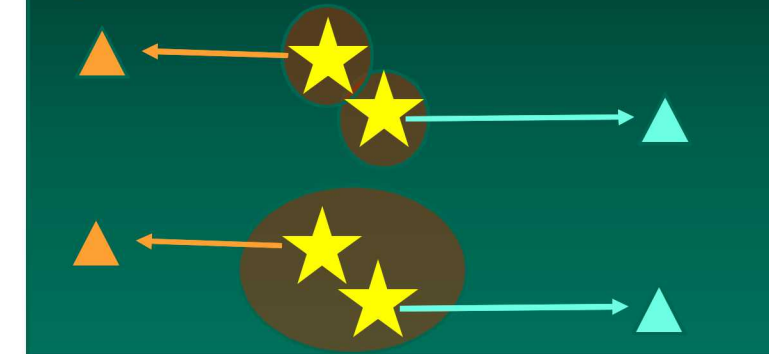
Detected by 3 templates



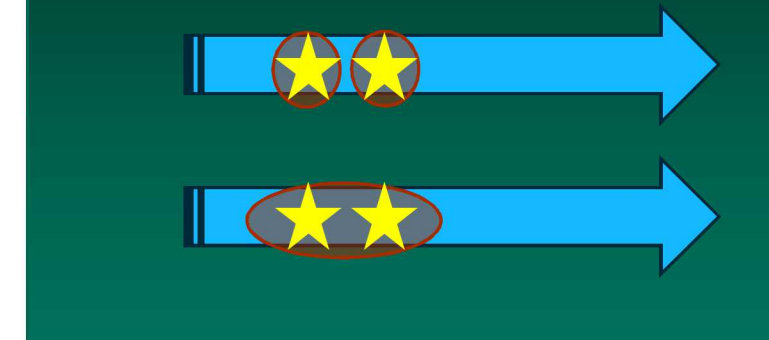
Multistation validation

- Are these 3 detections the same event?
- Aftershocks are close in space and time.
- Parameterization study to choose tolerances.

Spatial tolerance – one event or two?

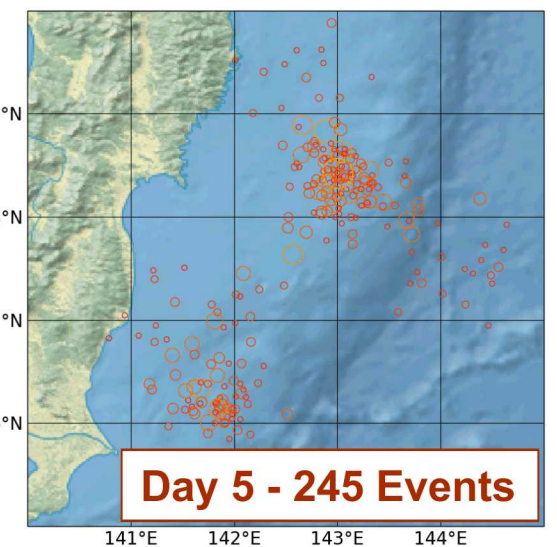
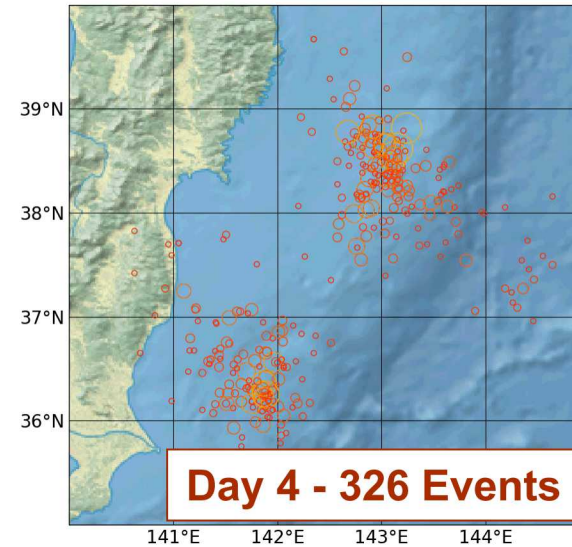
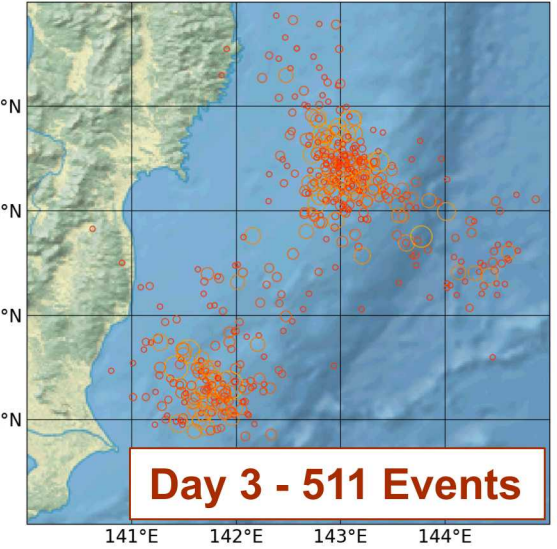
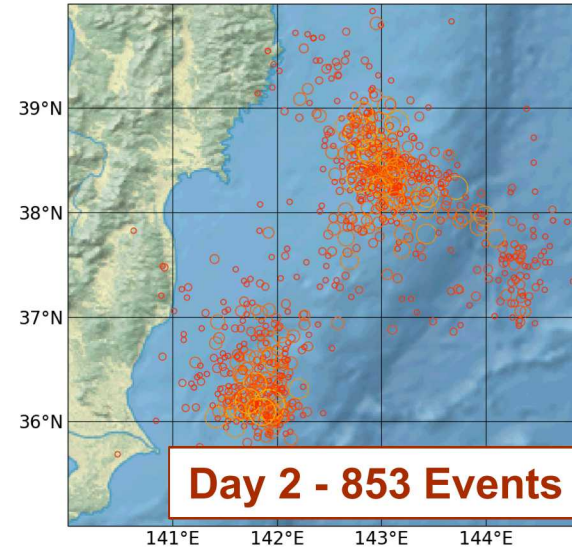
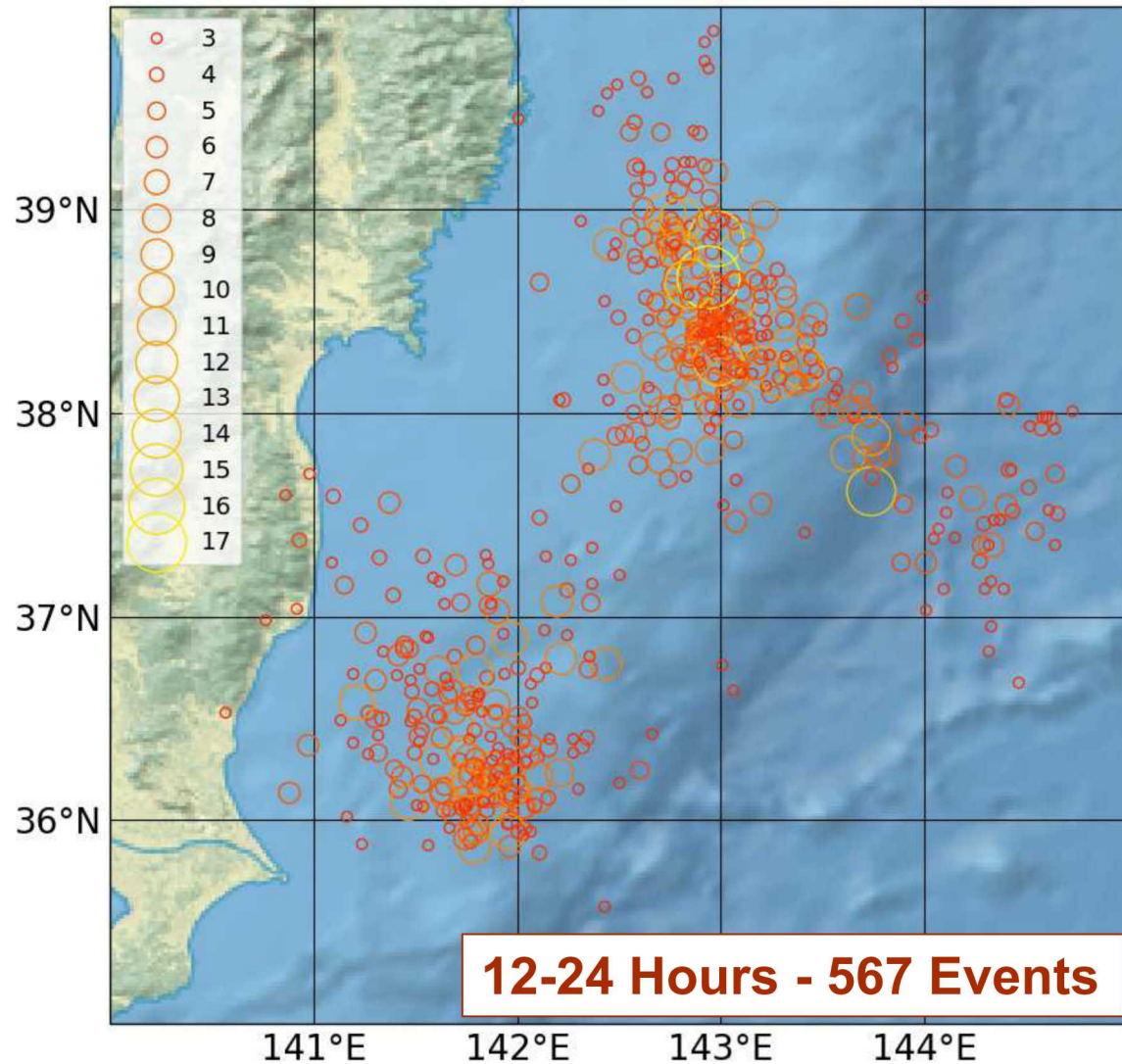


Time tolerance – one event or two?



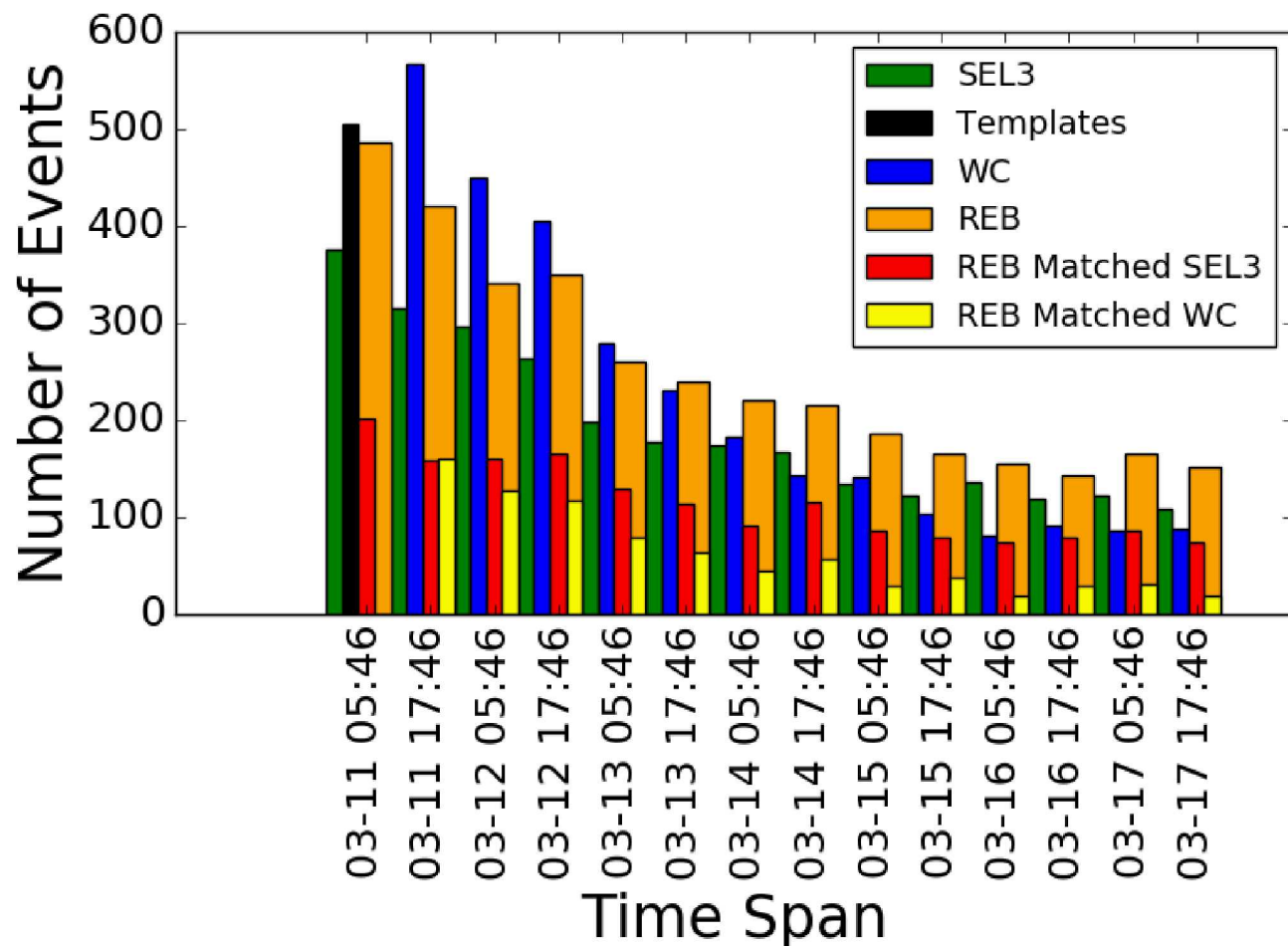
6 Tohoku 2011 Events Detected by Waveform Correlation

Location of events detected by 3 or more stations (or templates from different phases)

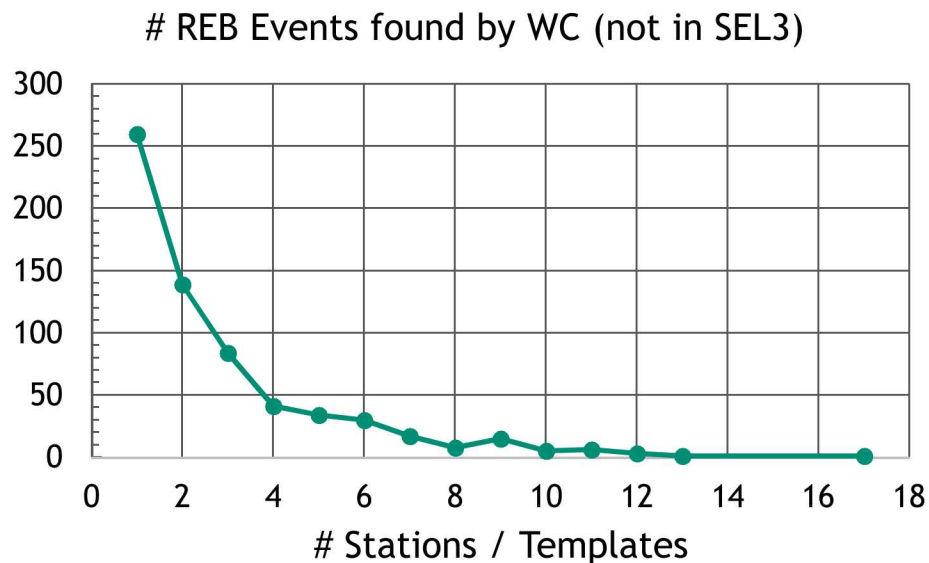


Tohoku 2011 WC Events compared with REB

Waveform correlation events were detected by 3 or more stations/templates.



- Bars show 12 hour increments of events.
- Multistation tolerances were 150 km, 30 s.
- REB comparison tolerances to SEL3 and WC events were 1.0° , ± 15 s.



Results: Workload reduction and effectiveness

Our metric for *estimated workload reduction* calculates a ratio of REB events detected by WC to the number of REB events the analysts built manually (i.e., events not in SEL3).

$$\text{Estimated Workload Reduction} = \frac{(\# \text{ REB events matching WC not in SEL3})}{(\# \text{ REB Events} - \# \text{ REB Events matching SEL3})} \times 100$$

Sequence	# REB events matching WC not in SEL3	# REB events	#REB events matching SEL3	Estimated Workload Reduction (WR)
Nepal 2015	139	250	57	72%
Chile 2015	68	487	182	22%
Tohoku 2011	624	3015	1415	39%

- WR includes existing performance of existing pipeline in calculation.
- WC events include NDEF ≥ 1 .

Results: Workload reduction and effectiveness

$$\text{Estimated Workload Reduction} = \frac{(\# \text{ REB events matching WC not in SEL3})}{(\# \text{ REB Events} - \# \text{ REB Events matching SEL3})} \times 100$$

Sequence	# REB events matching WC not in SEL3	# REB events	#REB events matching SEL3	Estimated Workload Reduction (WR)
Nepal 2015	139	250	57	72%
Chile 2015	68	487	182	22%
Tohoku 2011	624	3015	1415	39%

The metric for *estimated effectiveness* calculates a ratio of REB events detected by WC to the number of REB events; no dependence on SEL3.

$$\text{Estimated Effectiveness} = \frac{(\# \text{ REB events matching WC})}{(\# \text{ REB Events})} \times 100$$

Sequence	# REB events matching WC	# REB events	Estimated Effectiveness (EE)
Nepal 2015	179	250	72%
Chile 2015	175	487	36%
Tohoku 2011	1494	3015	50%

- WR includes existing performance of existing pipeline in calculation.
- EE does not depend on performance of existing pipeline.
- WC events include $NDEF \geq 1$.

Aftershock Challenges and Future Work

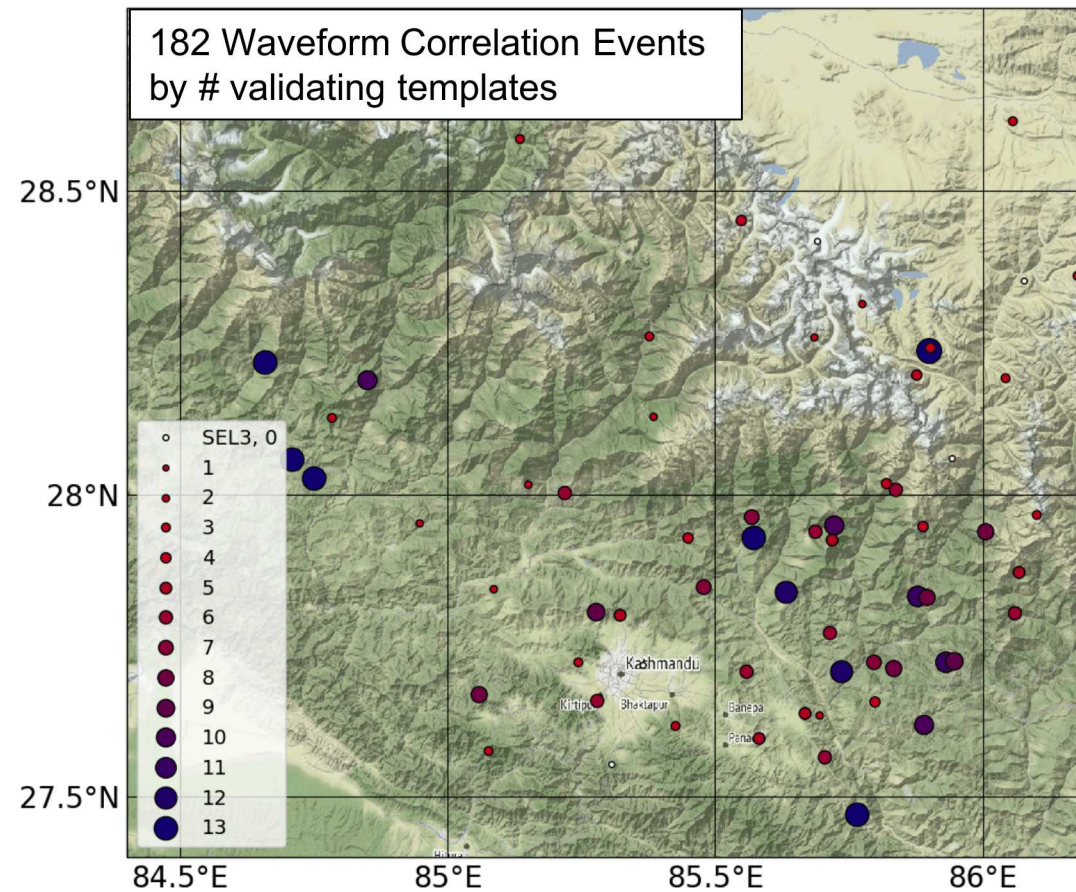
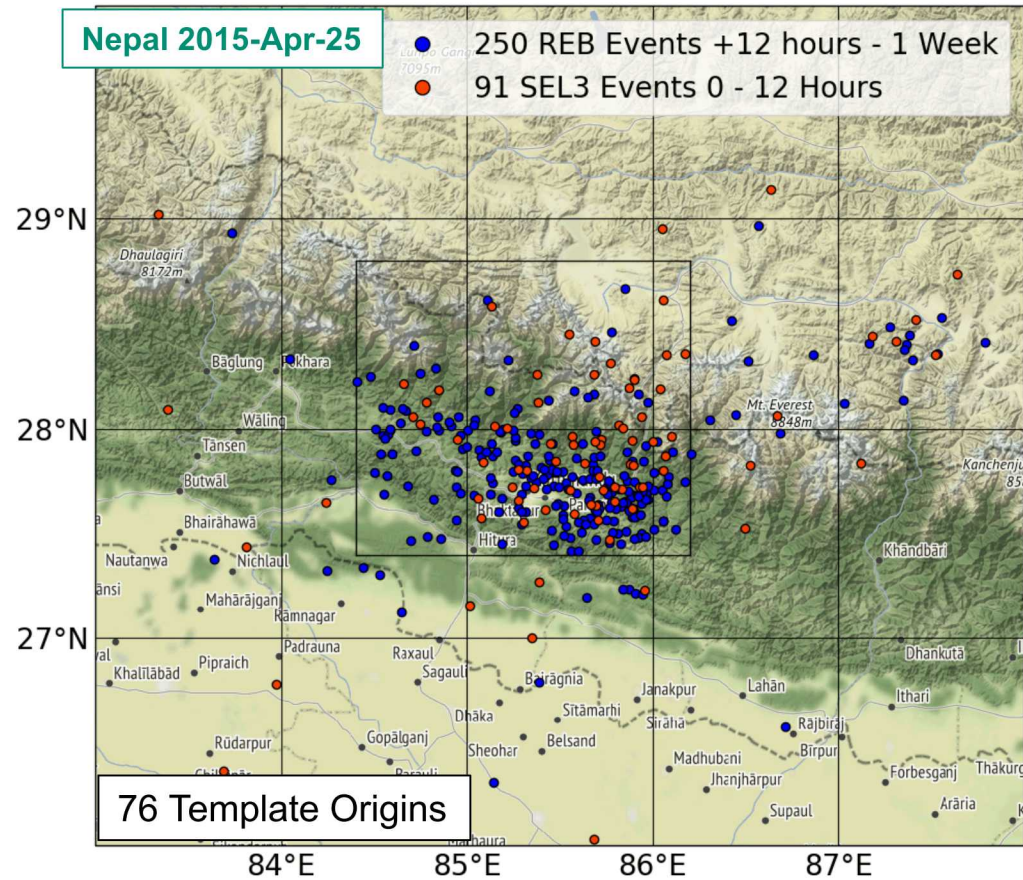
- Creating good templates from aftershock waveforms is difficult due to the potential for overlapping events. This study used short (15 s) templates, yet still saw some examples of overlapping events.
- This study included an analysis of tolerances for multistation validation of correlation detections. Our results indicate that clustering detections for aftershock events that are close in space and time will be difficult and deserves more in-depth research.
- Waveform correlation detects small magnitude events, and we have no ground truth to estimate a false positive rate.
- Specific recommendations for future research:
 - Template selection/grooming to ensure high quality templates.
 - Develop techniques to select which waveform correlation detections will be useful for the analysts.

Summary

- Results suggest that waveform correlation is capable of improving the effectiveness of the IDC pipeline during aftershock processing.
- Tuning the pipeline associator to make optimal use of waveform correlation detections during an aftershock sequence may require substantial effort.
- Report: Sundermier, A., R. Tibi, and C. J. Young (2019). Applying Waveform Correlation to Aftershock Sequences Using a Global Sparse Network, *Technical Report SAND2019-10184*.
- Thank you for inviting SNL to participate in the PTS Recurring Events study of waveform correlation techniques!

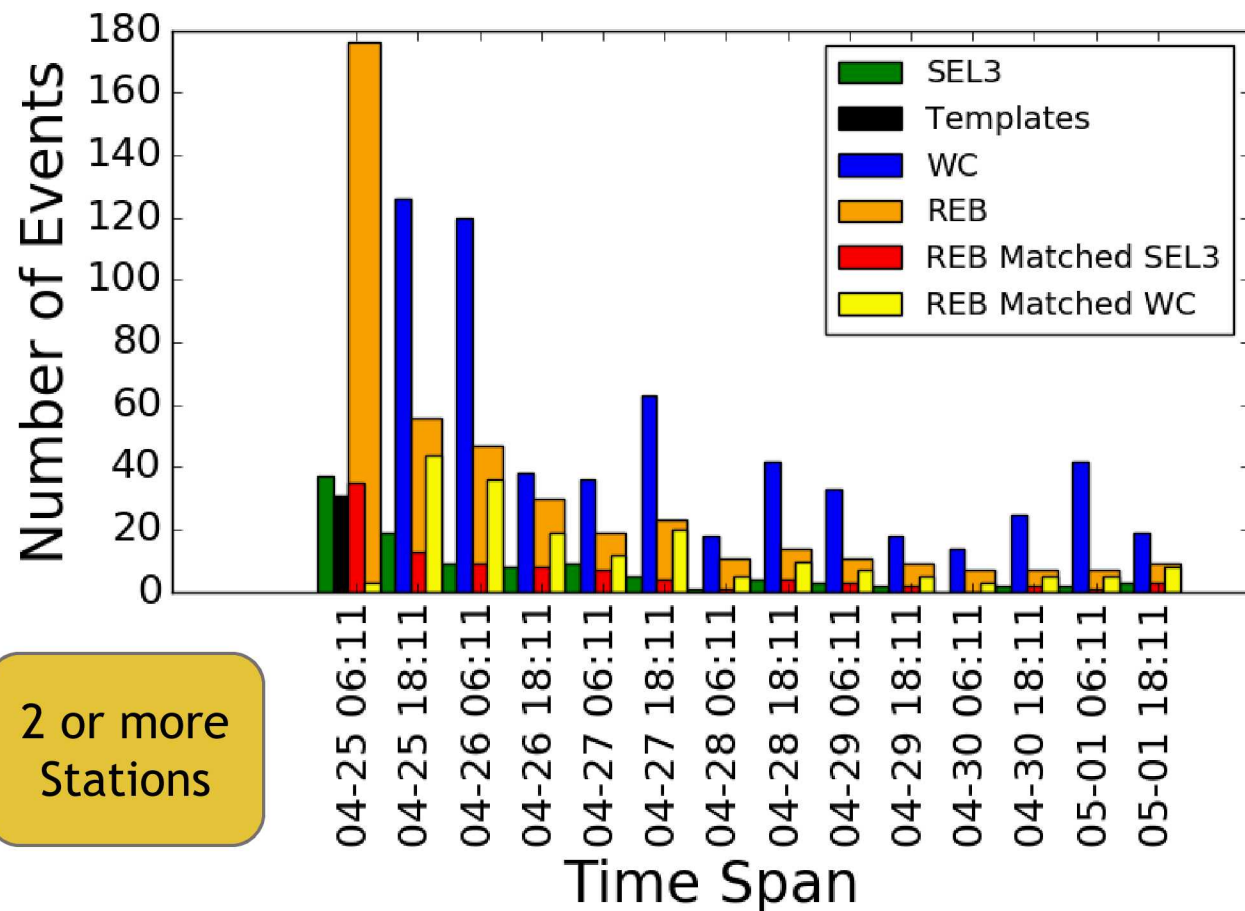


Nepal 2015 Templates and Waveform Correlation Events

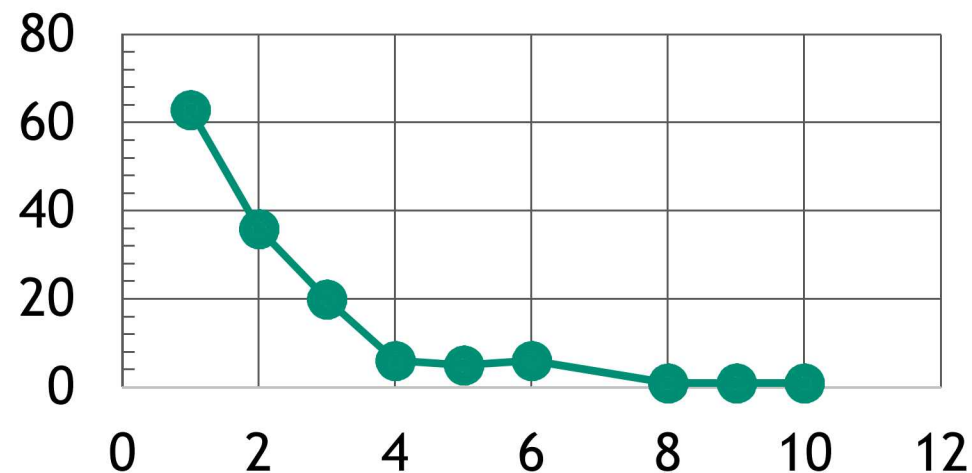


Nepal 2015 WC Events compared with REB

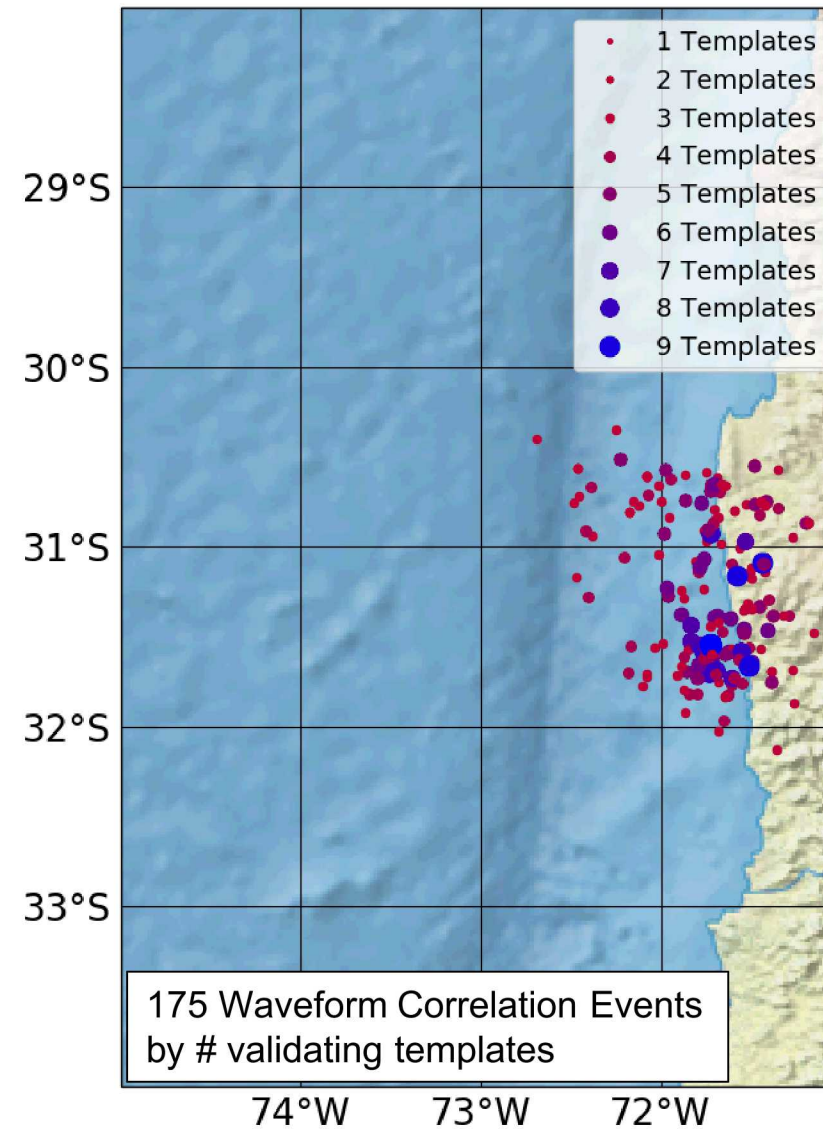
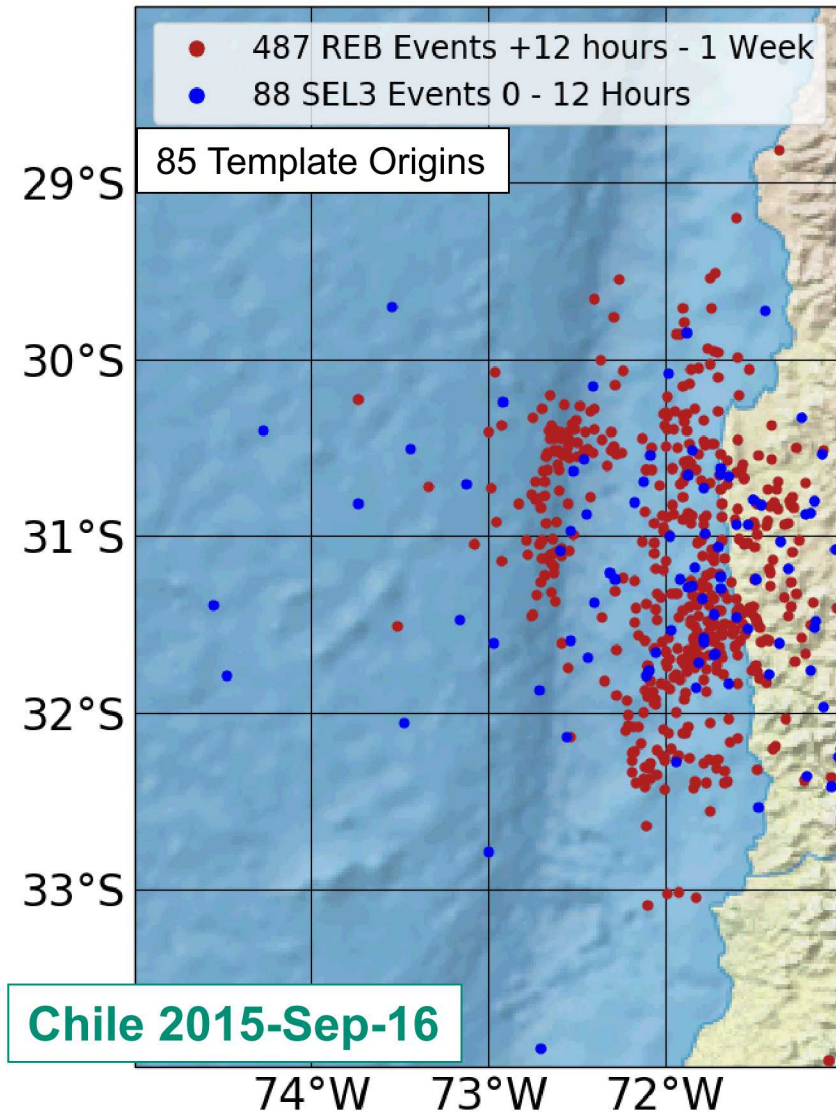
Waveform correlation events were detected by 2 or more stations/templates.



Nepal: # REB Events not in SEL3 found by WC; by # Stations

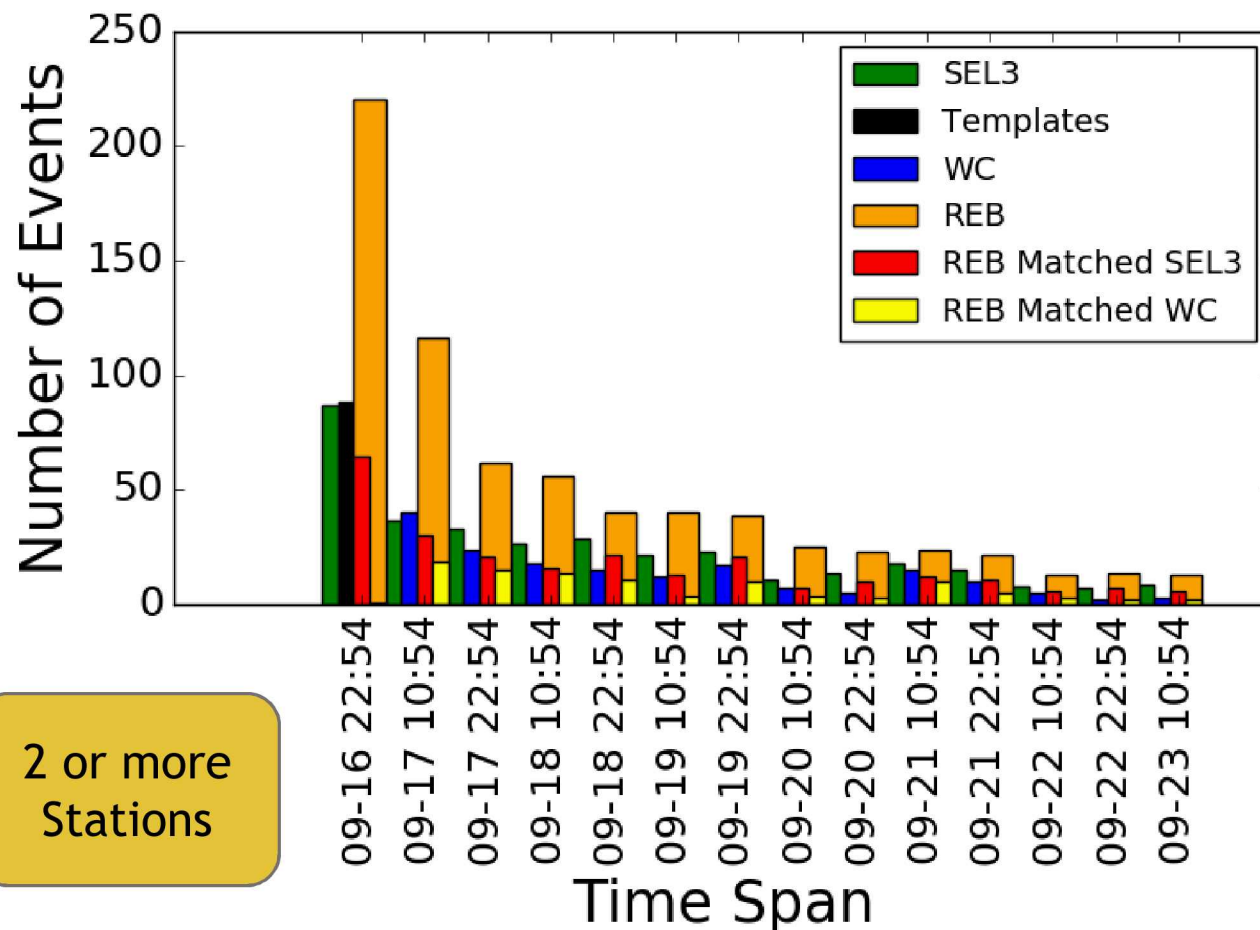


Chile 2015 Templates and Waveform Correlation Events



Chile 2015 WC Events compared with REB

Waveform correlation events were detected by 2 or more stations/templates.



2 or more
Stations

Time Span (12 Hour Increments)

Chile: # REB Events not in SEL3
found by WC; by # Stations

