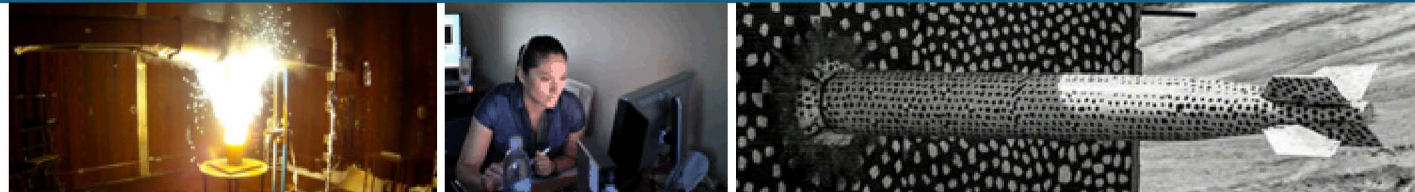


Using waveform correlation to reduce analyst workload due to repeating mining blasts



Amy Sundermier, Rigobert Tibi, Christopher J. Young

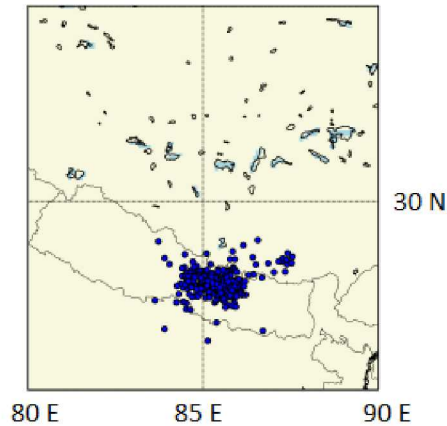


Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

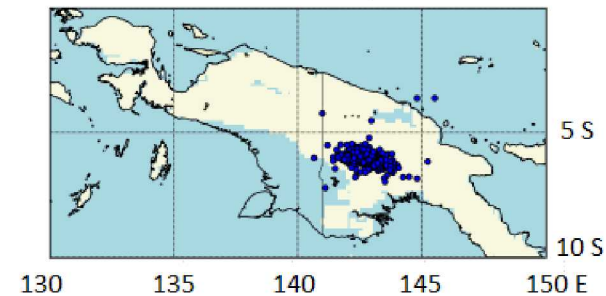
Provisional Technical Secretariat (PTS) Initiated Study of Waveform Correlation Techniques to Detect 2 Types of Recurring Events

Aftershocks

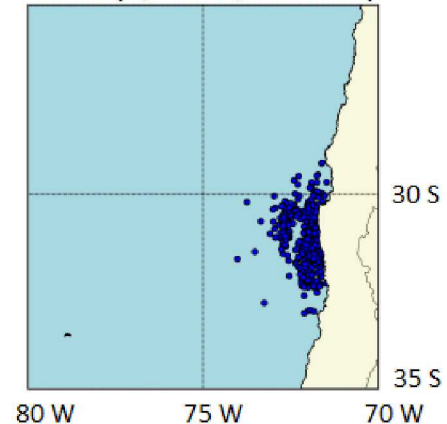
Nepal (4/2015, 7.8 Mw)



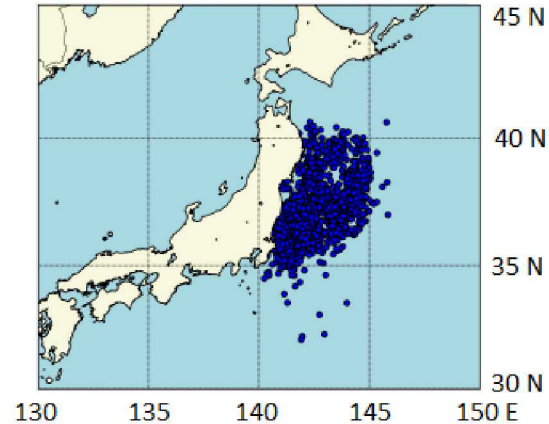
Papua New Guinea (2/2018, 7.5 Mw)



Chile (9/2015, 8.3 Mw)

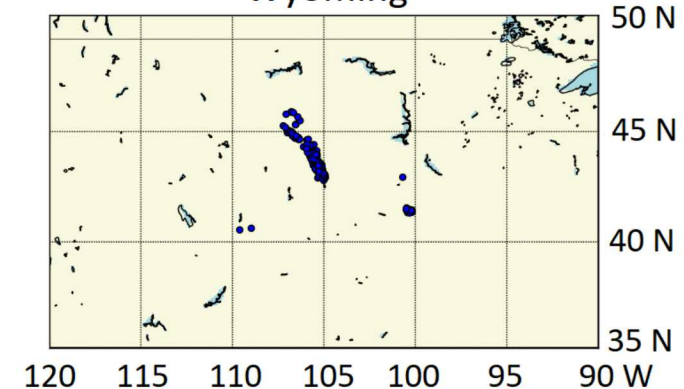


Tohoku (3/2011, 9.0-9.1 Mw)

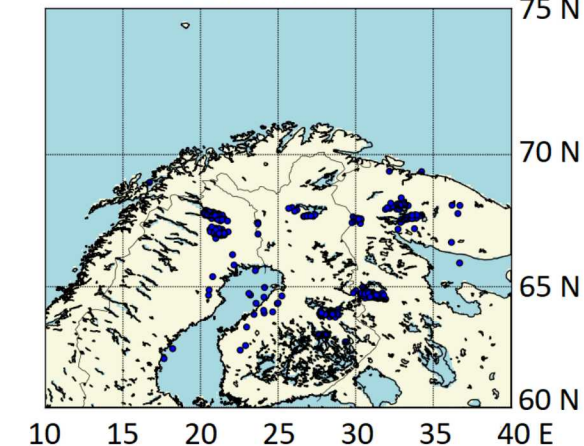


Mining Blasts

Wyoming



Scandinavia



3 Mining Blasts Study

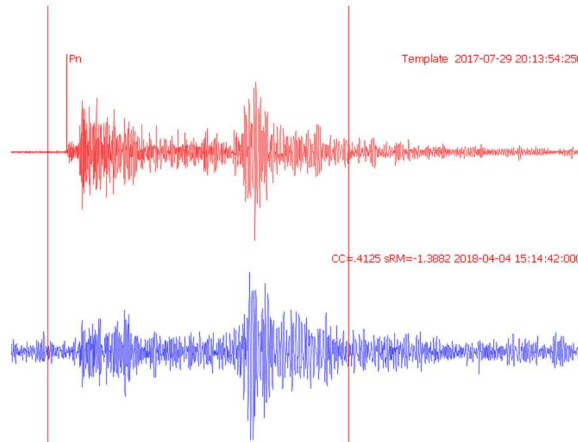
Experimental Setup

- Up to 10 years of templates for 3 stations prior to week of study
- Correlate over two 1-week periods

Timeline



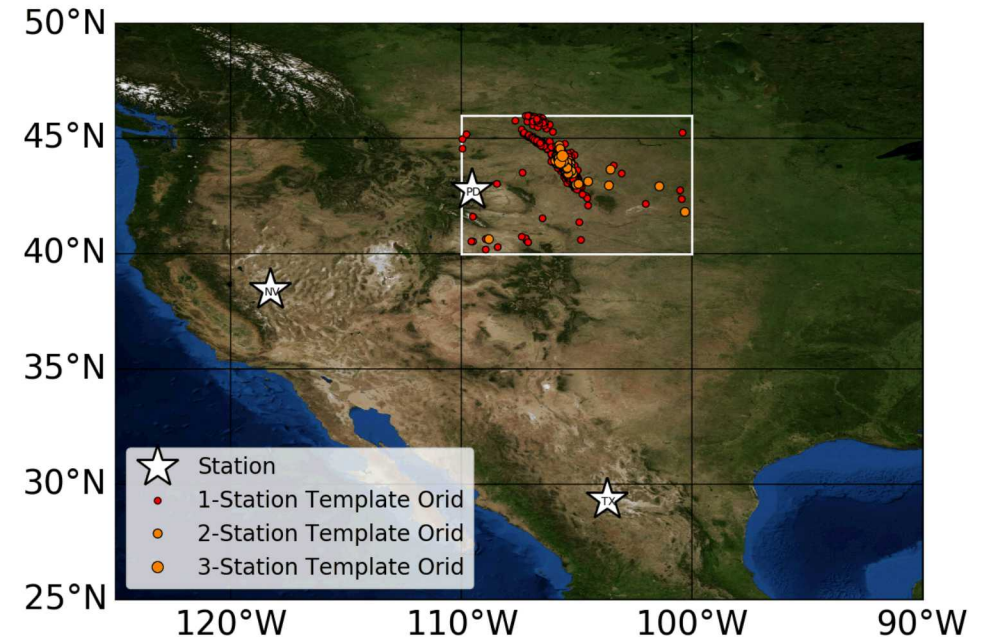
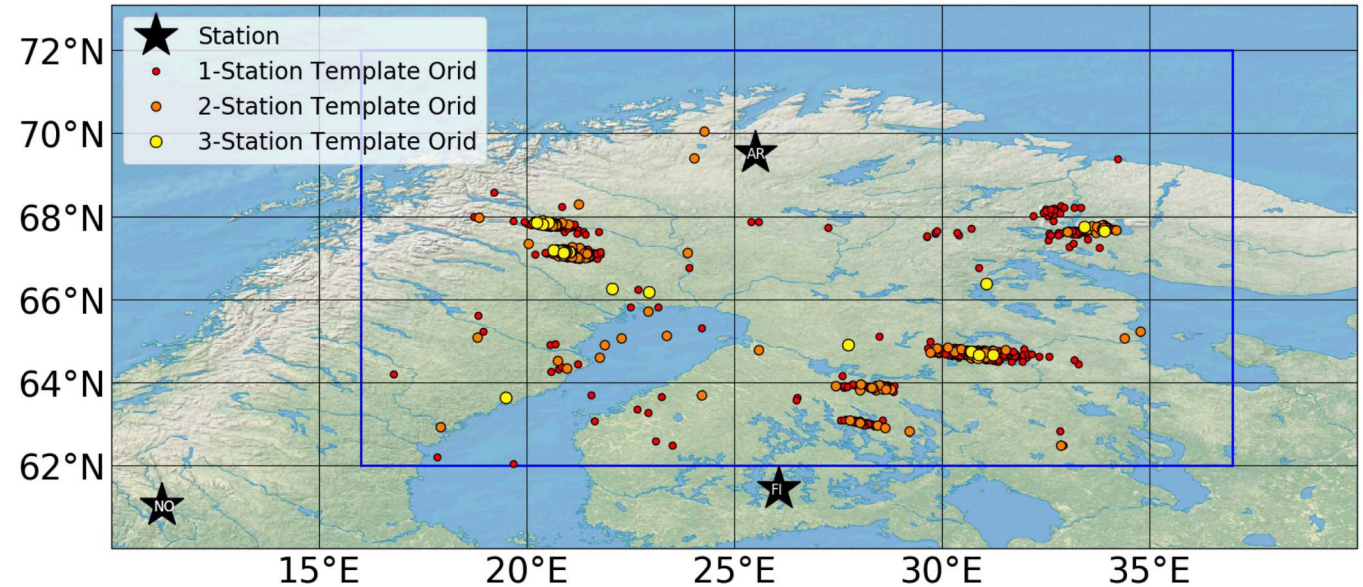
Example Template
PDAR, 80 s, Pn phase



Detection

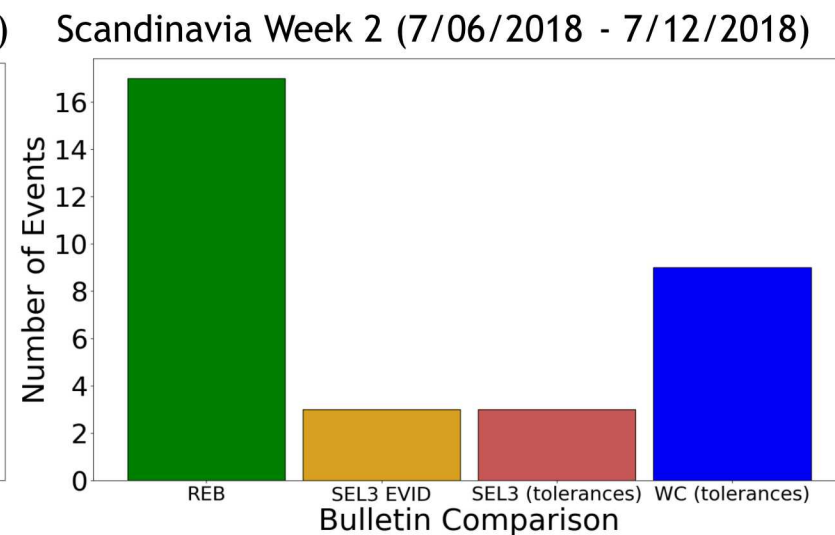
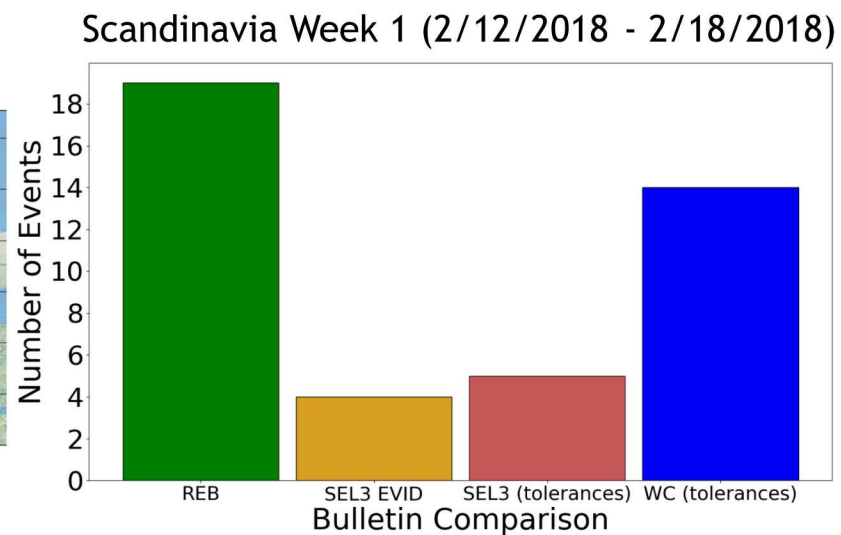
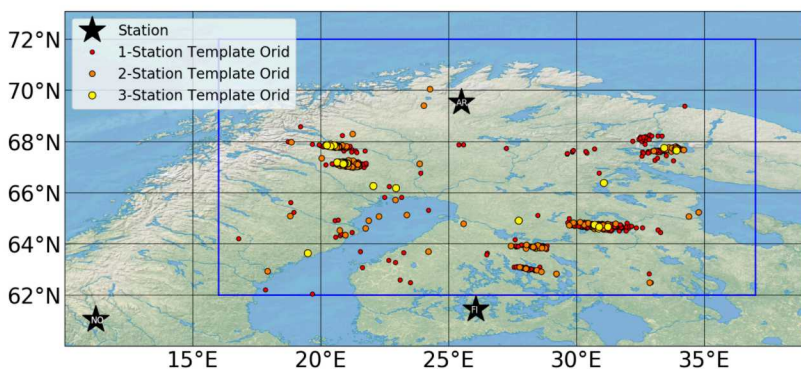
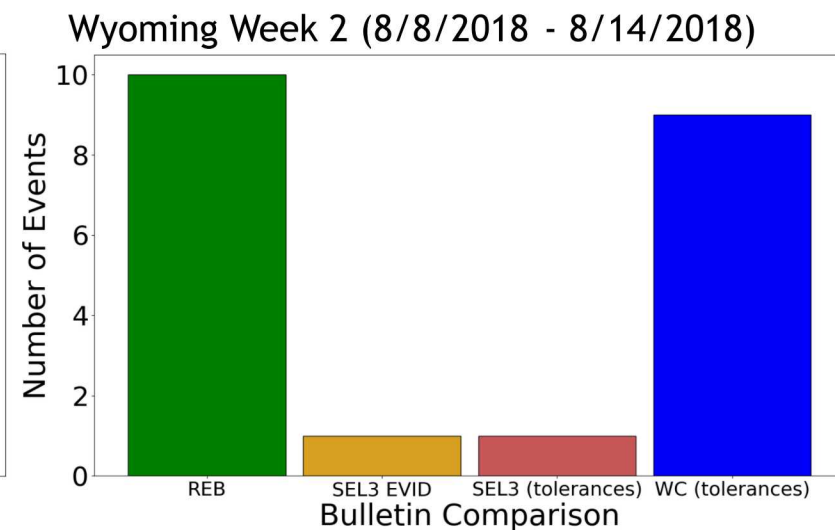
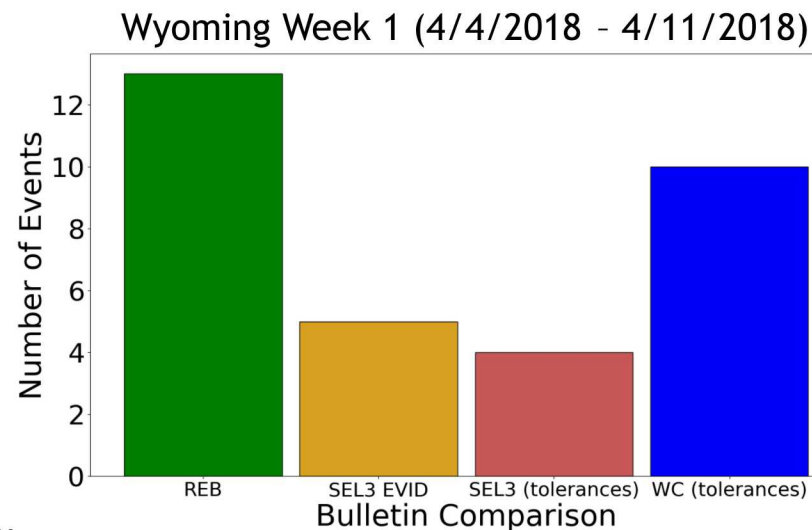
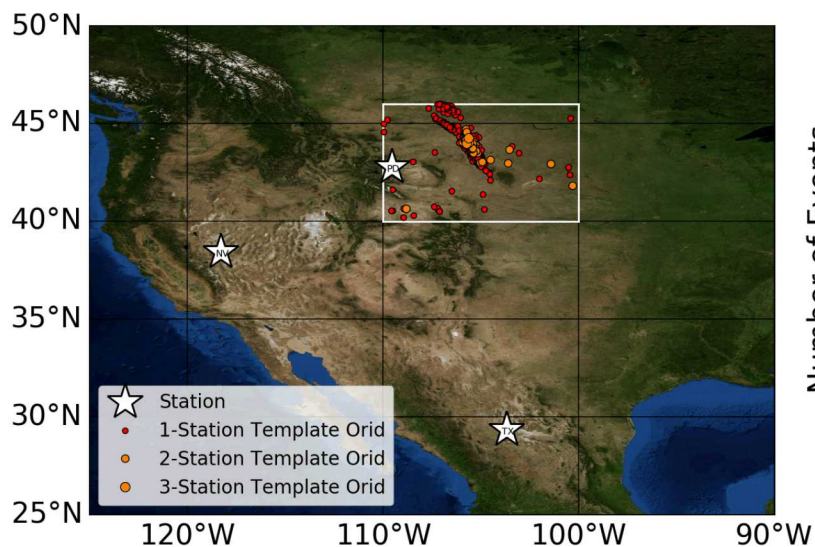
CC score = 0.4125

composite score for 13 elements of PDAR



Results Overview

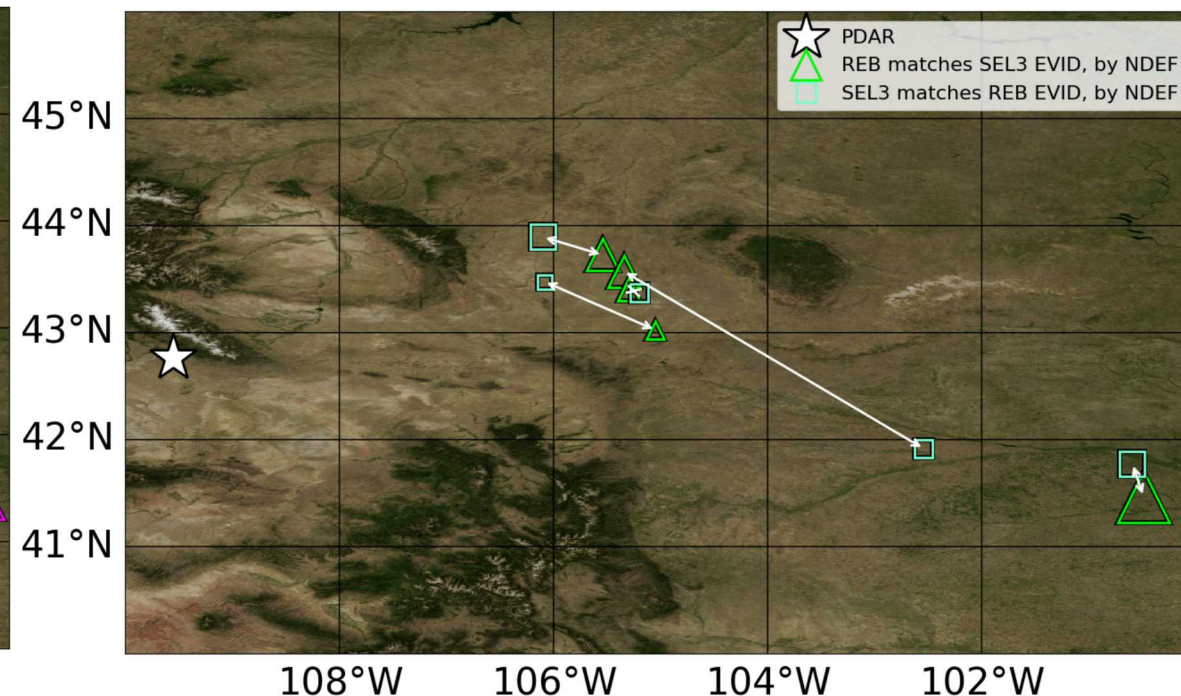
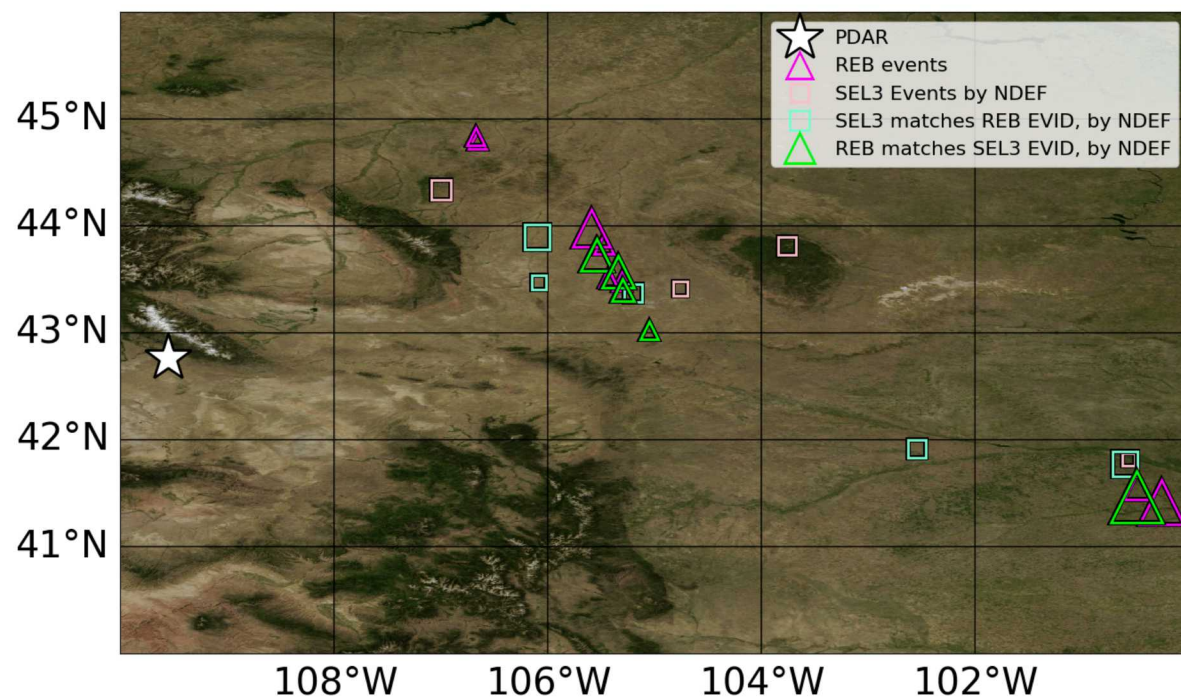
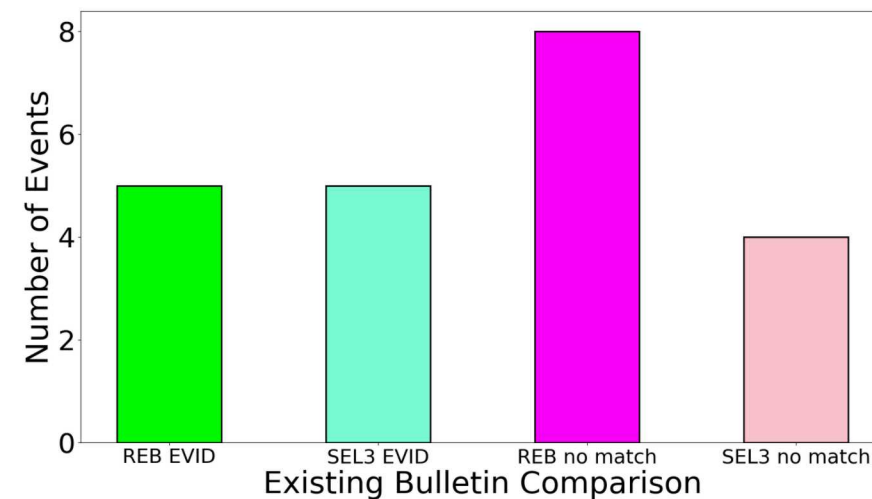
Event comparison tolerances (1.0° , $\pm 15s$)



Wyoming Week I (4/4/2018 – 4/11/2018)

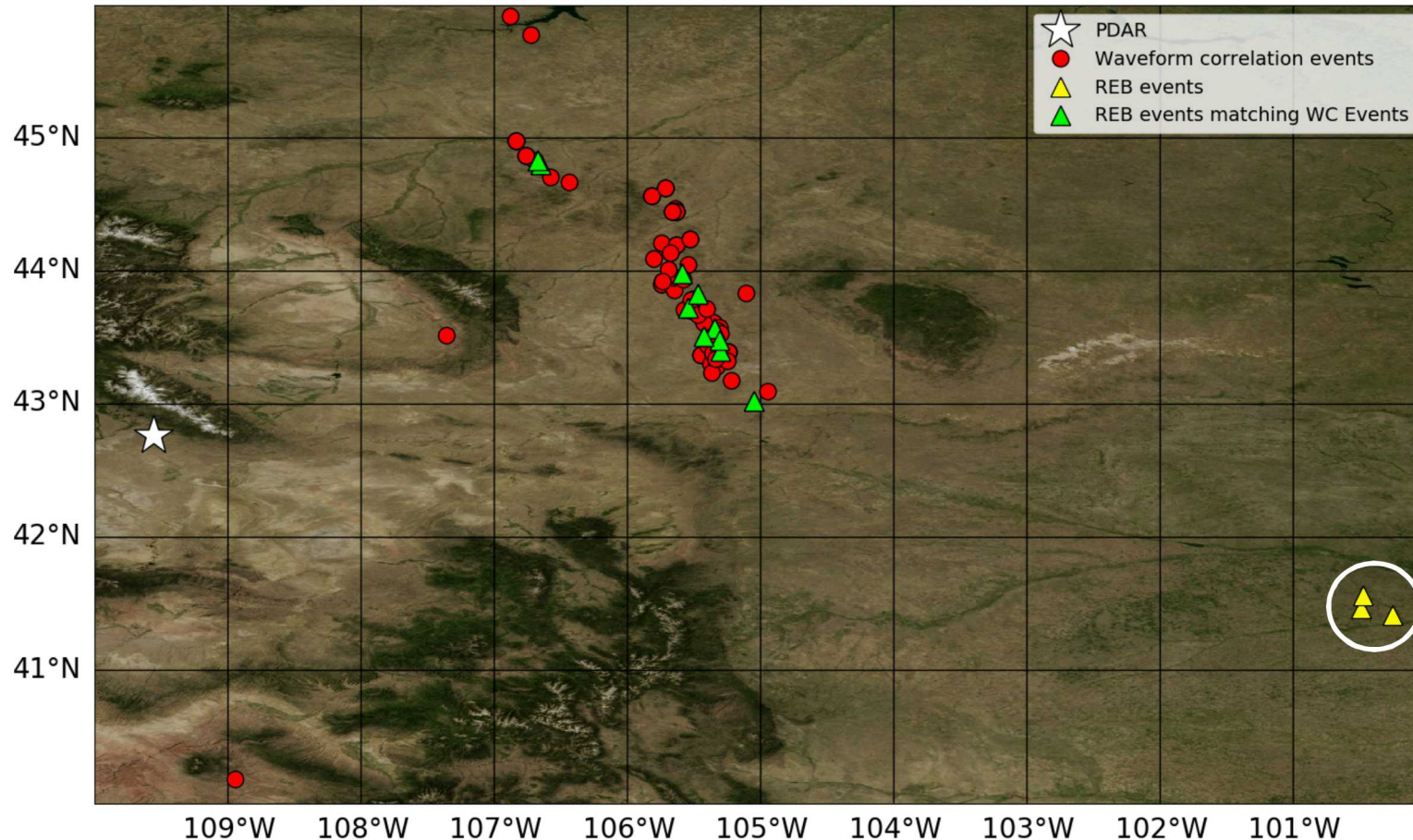
Overview of existing bulletins

- 9 SEL3 Events in region/week
- 5 SEL3 Event EVIDs = REB Event EVIDs
- 4 REB Events EVIDs $\neq$ SEL3 Event EVIDs
- 13 REB Events in region/week



Review: Single station (PDAR) results for Wyoming

- Wyoming region, week 1 (April 4-11, 2018) has **13** REB events in the study region.
- WC detected **10 of 13** REB events using 1 year of templates from PDAR station only.
- The tolerances for comparison are 0.5° , ± 10 s.



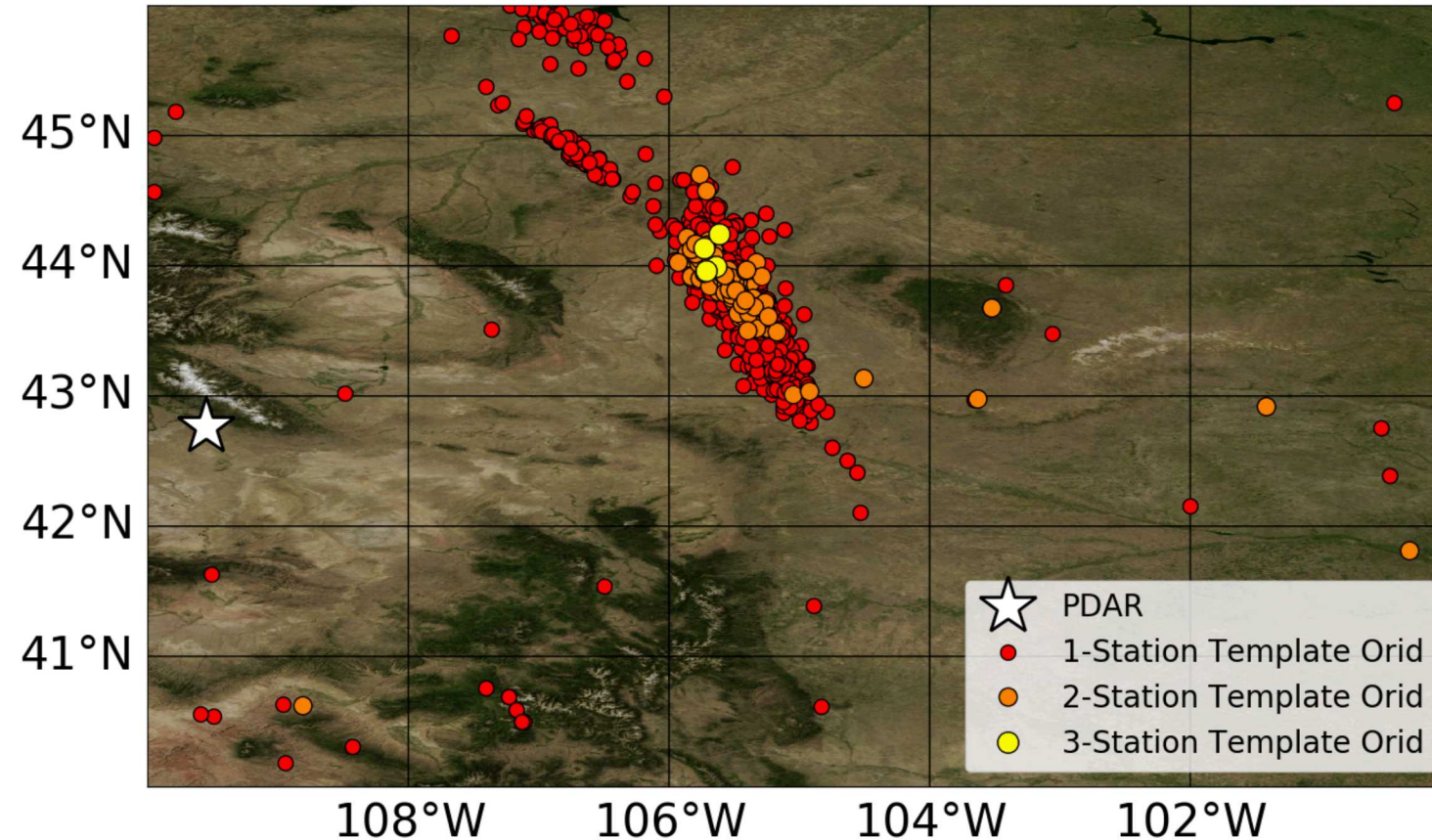
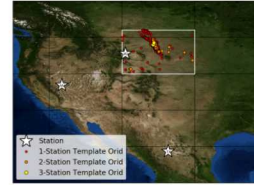
The **3** undetected events are from an area with no templates; thus, detection is not expected with this technique.

Waveform correlation detected 70 events during April 4-11, 2018 with PDAR templates.

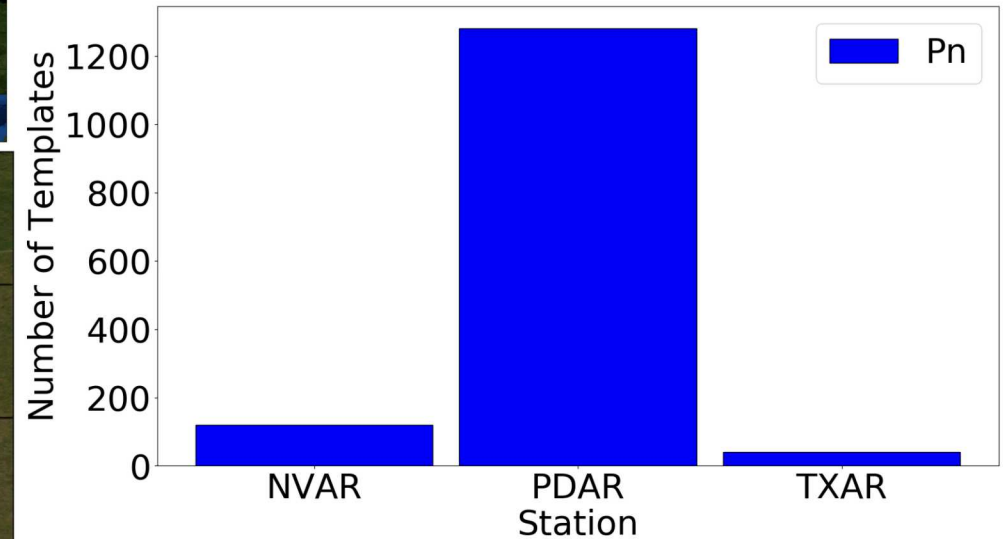
PDAR is close ($\sim 3^\circ$) to Wyoming region; results may be extraordinarily good.

Wyoming Week I (4/4/2018 - 4/11/2018) Templates

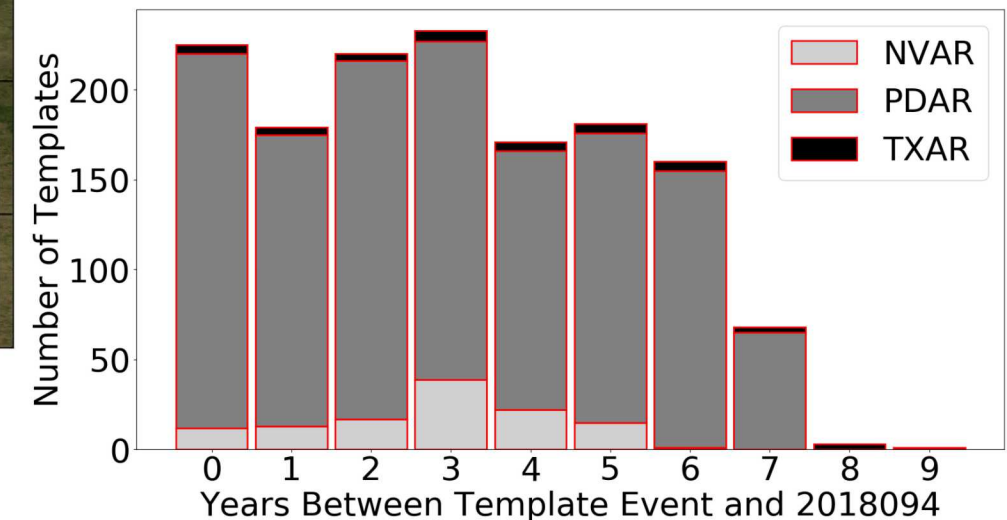
Map of study area showing 1303 template locations by number of stations (1-3) from up to 10 years of REB events.



Number of templates by station

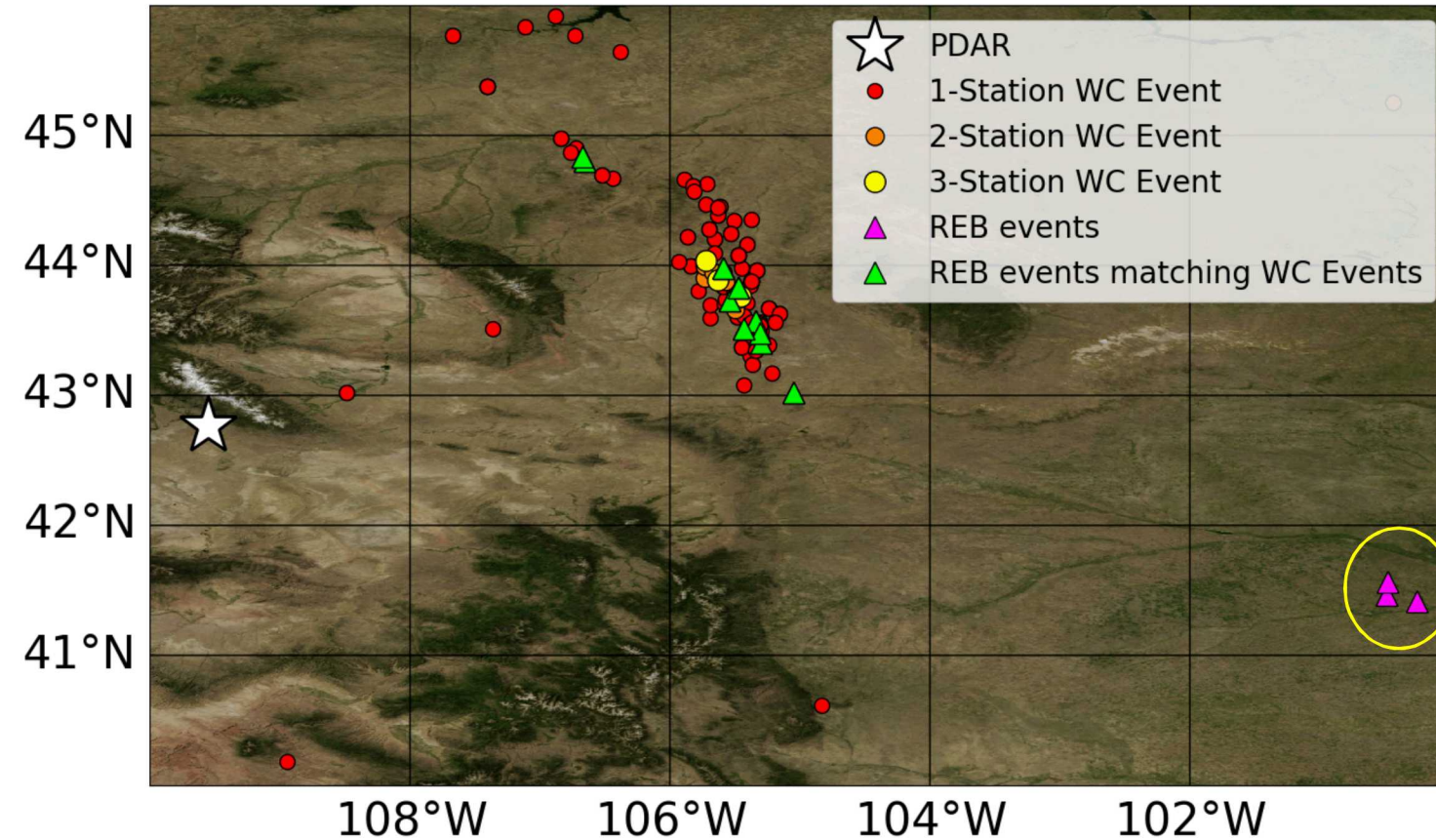


Age of templates (years) by station

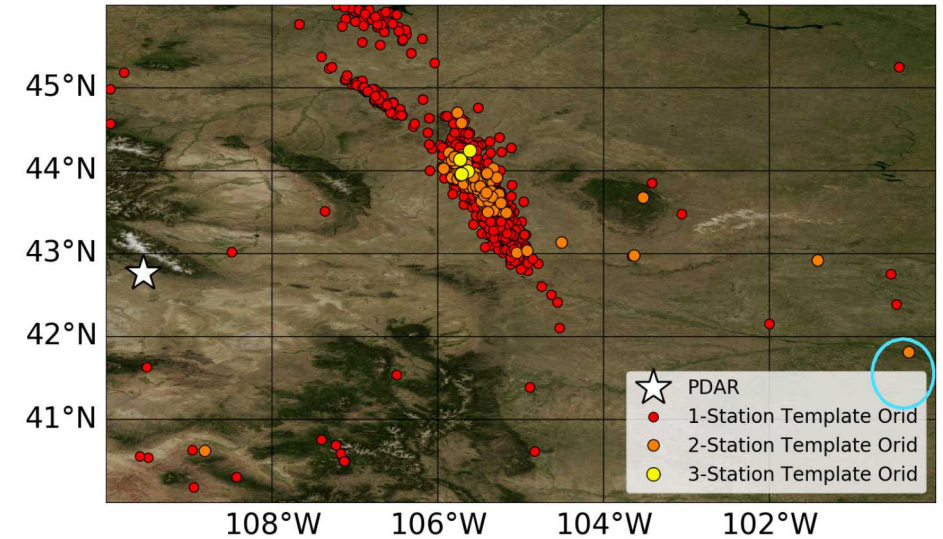


Wyoming Week I Waveform Correlation Events

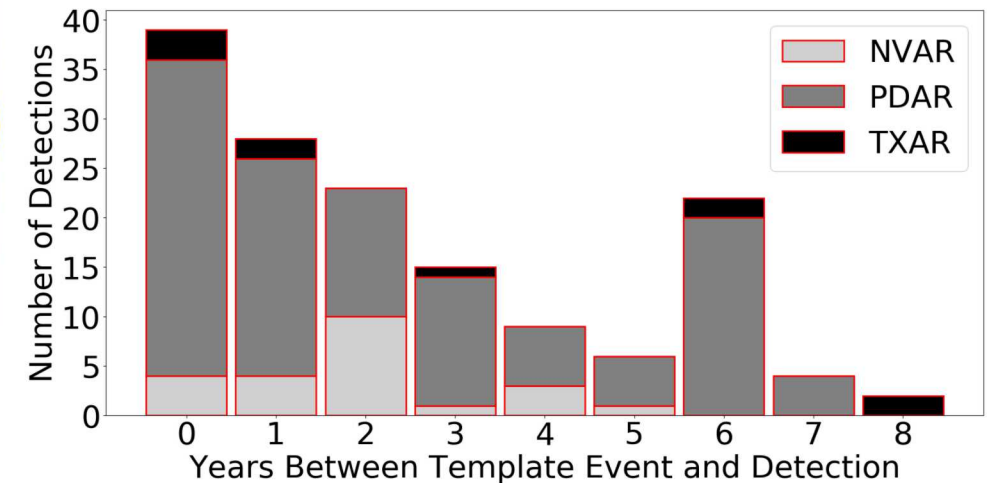
Map showing 136 waveform correlation and 13 REB event locations



Template Events near Missed REB events

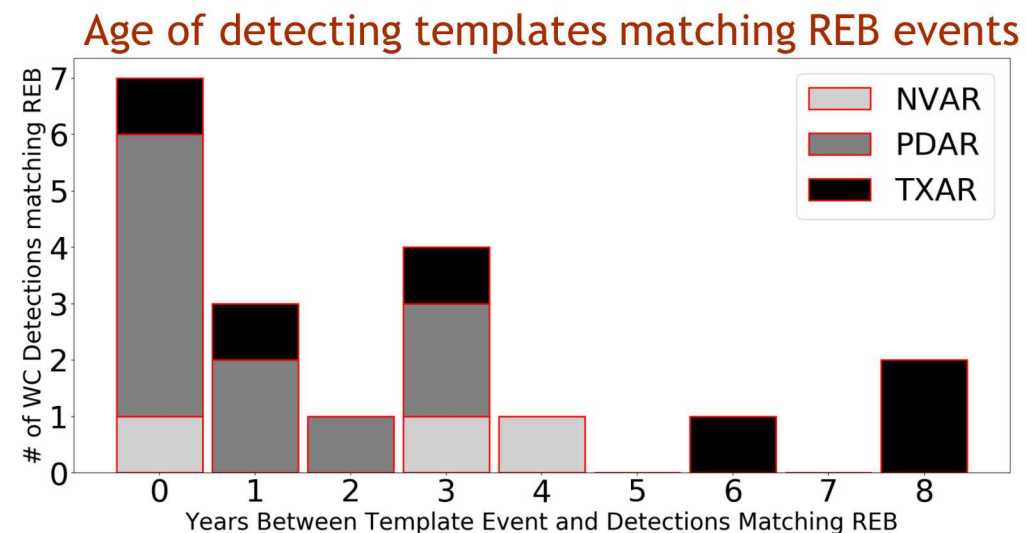
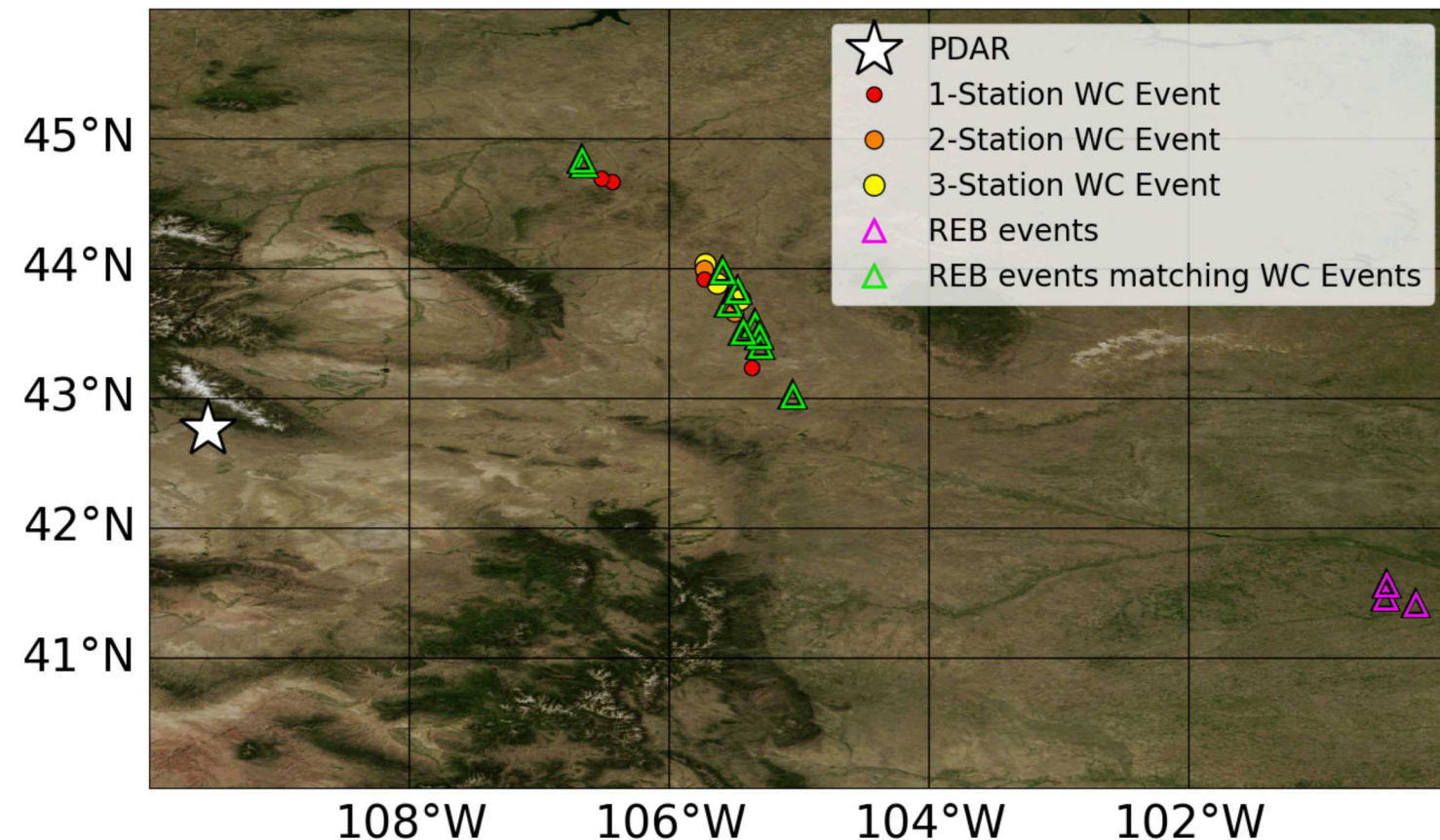


Age of detecting templates (years)



Wyoming Week I REB Event Matches

Map showing 13 REB event locations and
10 waveform correlation events within (1° , $\pm 15s$)

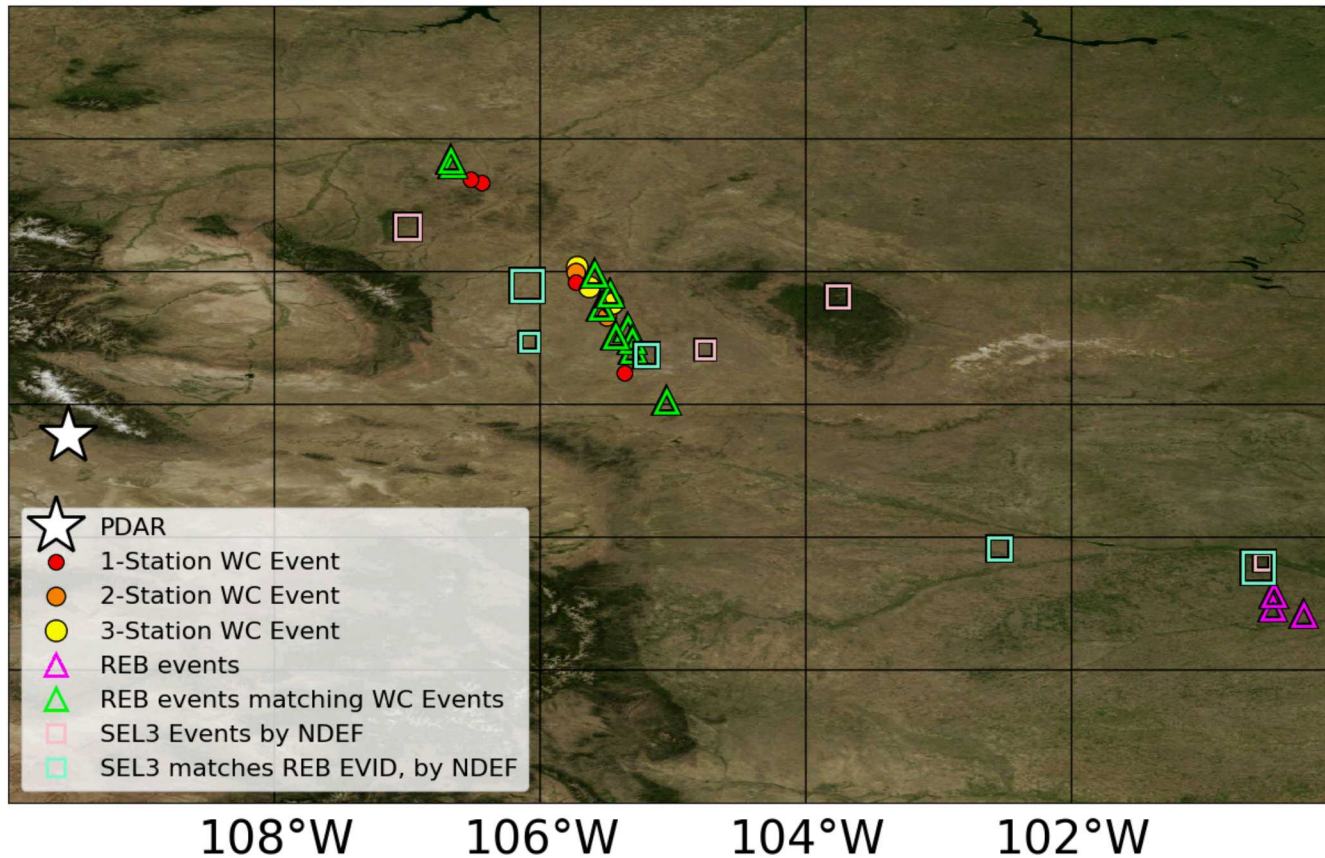


Wyoming Week I Comparing WC and SEL3 with REB Events

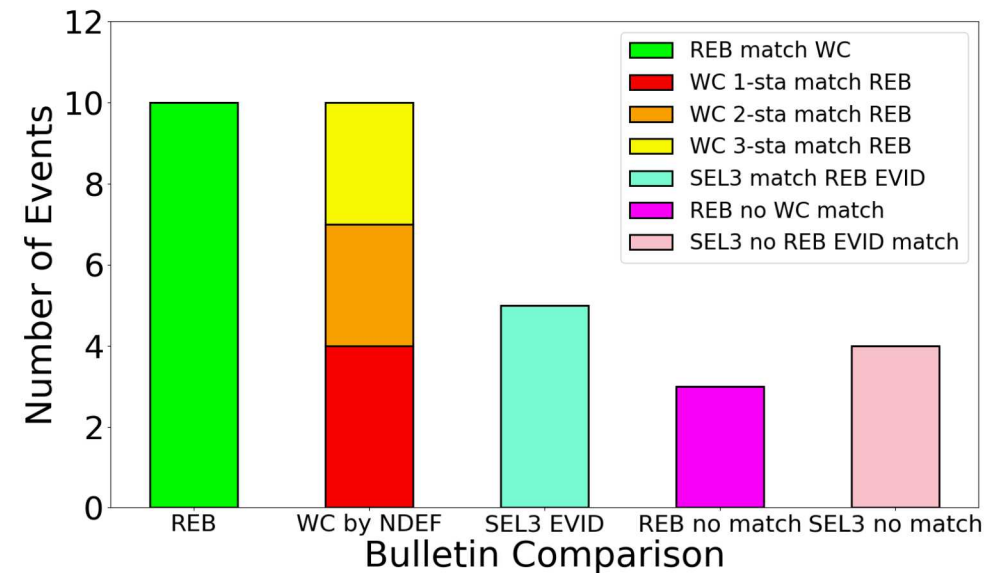
Map showing 13 REB events, 9 SEL3 events, and 10 waveform correlation events within (1° , $\pm 15s$)

Notes for Wyoming Week 1

- Waveform correlation locations are more accurate than SEL3
- Are the other 126 WC events valid?



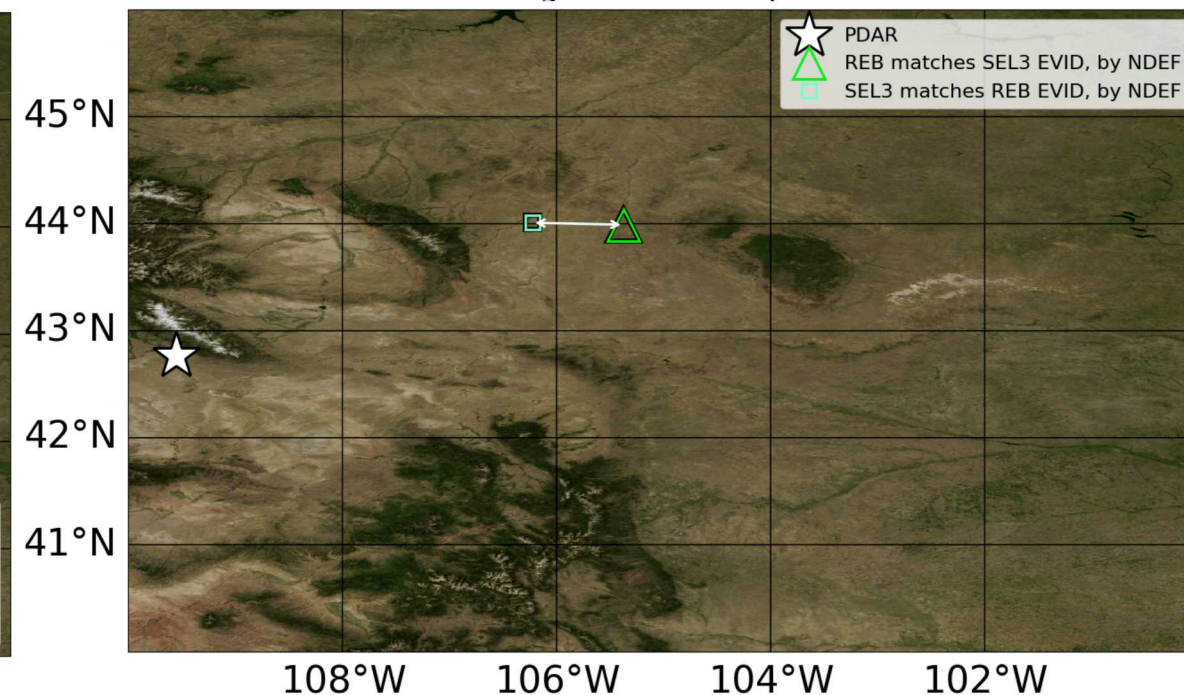
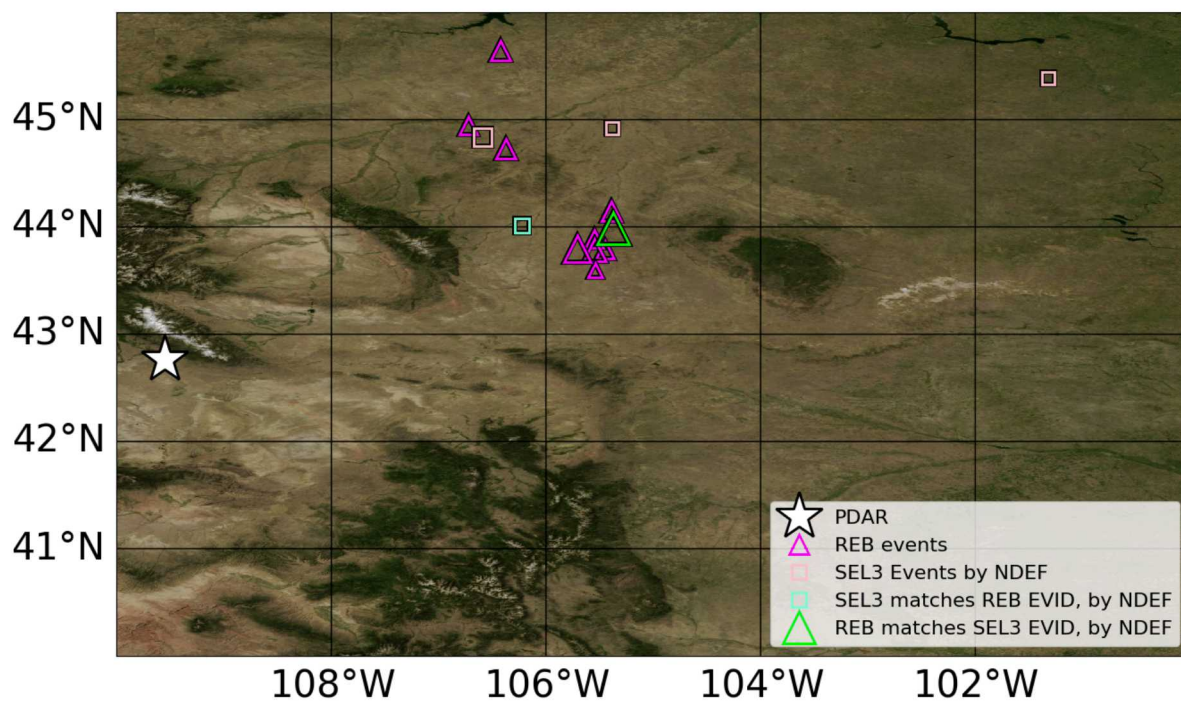
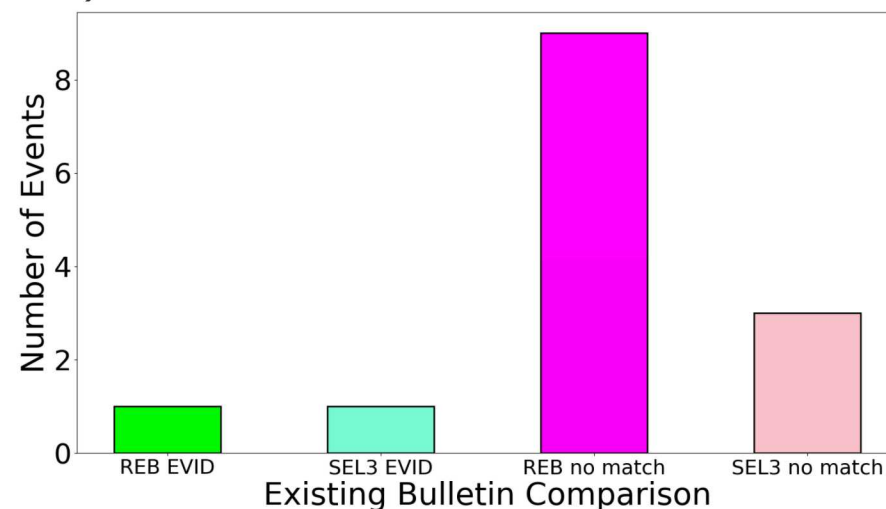
Bulletin Comparison for Wyoming Week 1



Wyoming Week 2 (8/8/2018 - 8/14/2018)

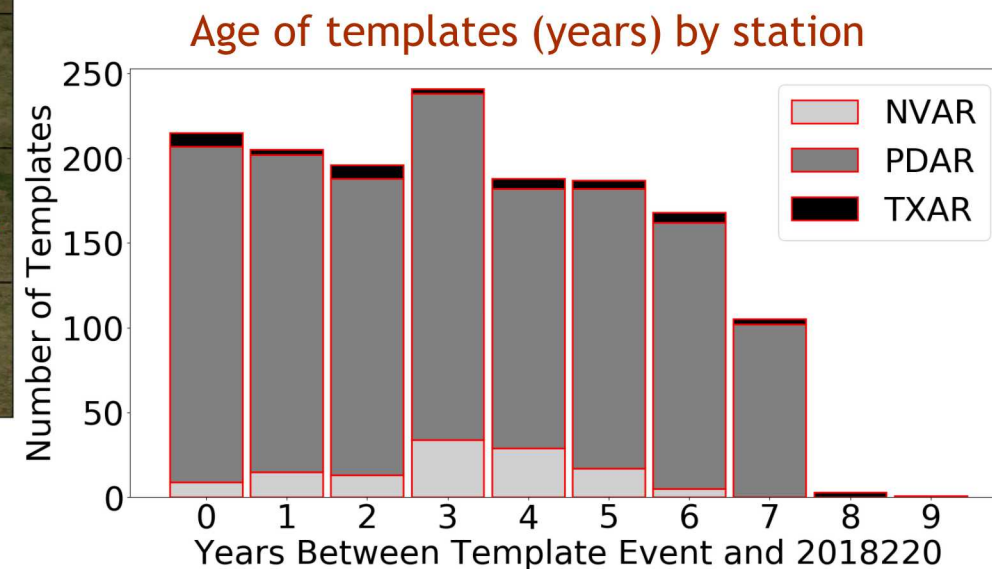
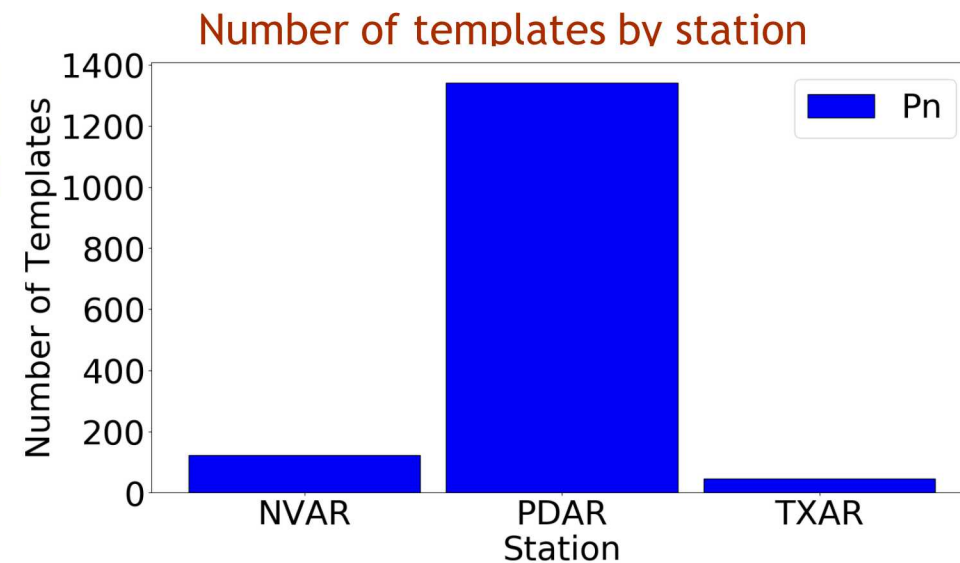
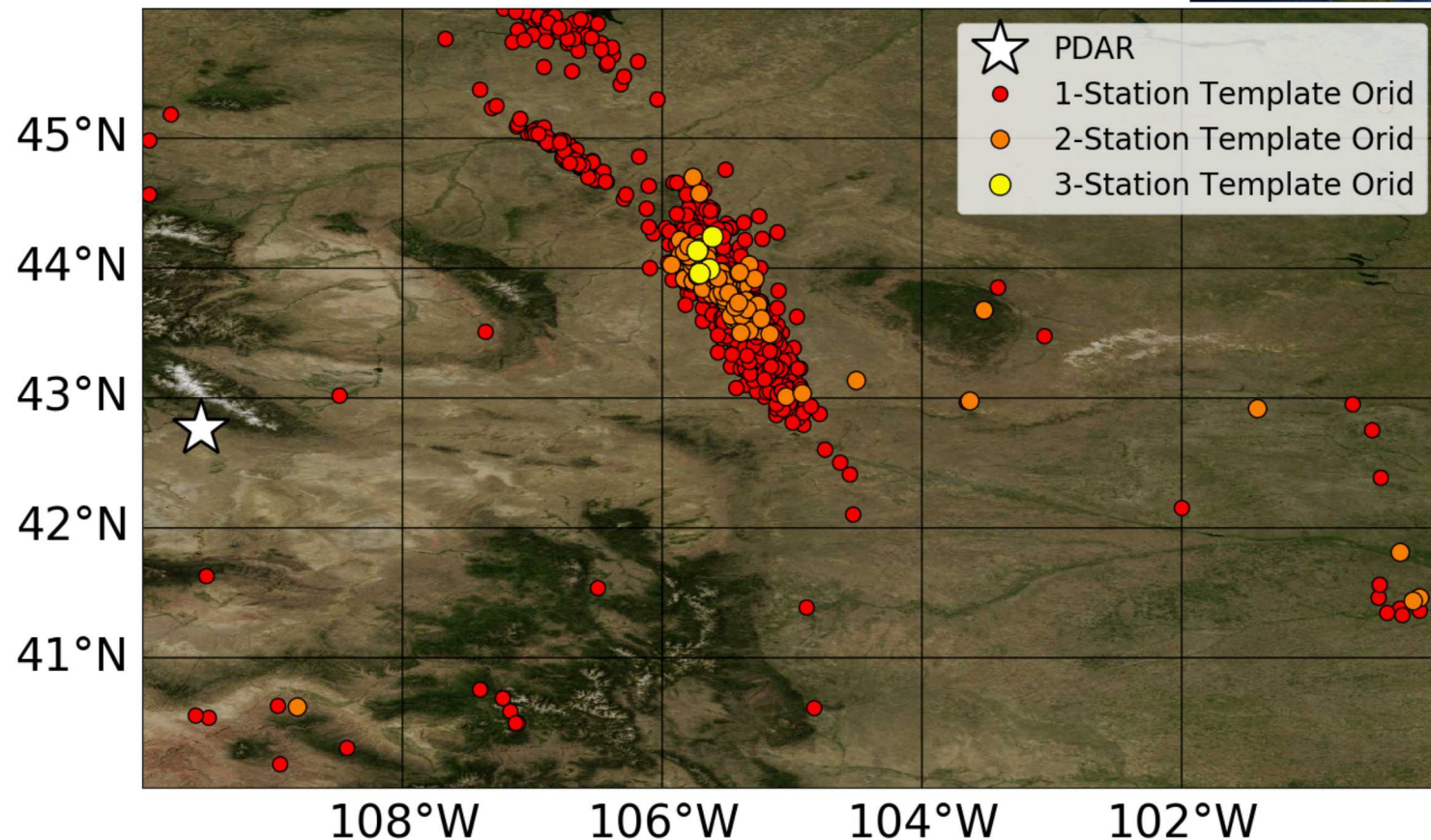
Overview of existing catalogs

- 4 SEL3 Events in region/week
- 1 SEL3 Event EVID = REB Event EVID
- 3 REB Event EVIDs $\neq$ SEL3 Event EVIDs
- 10 REB Events in region/week



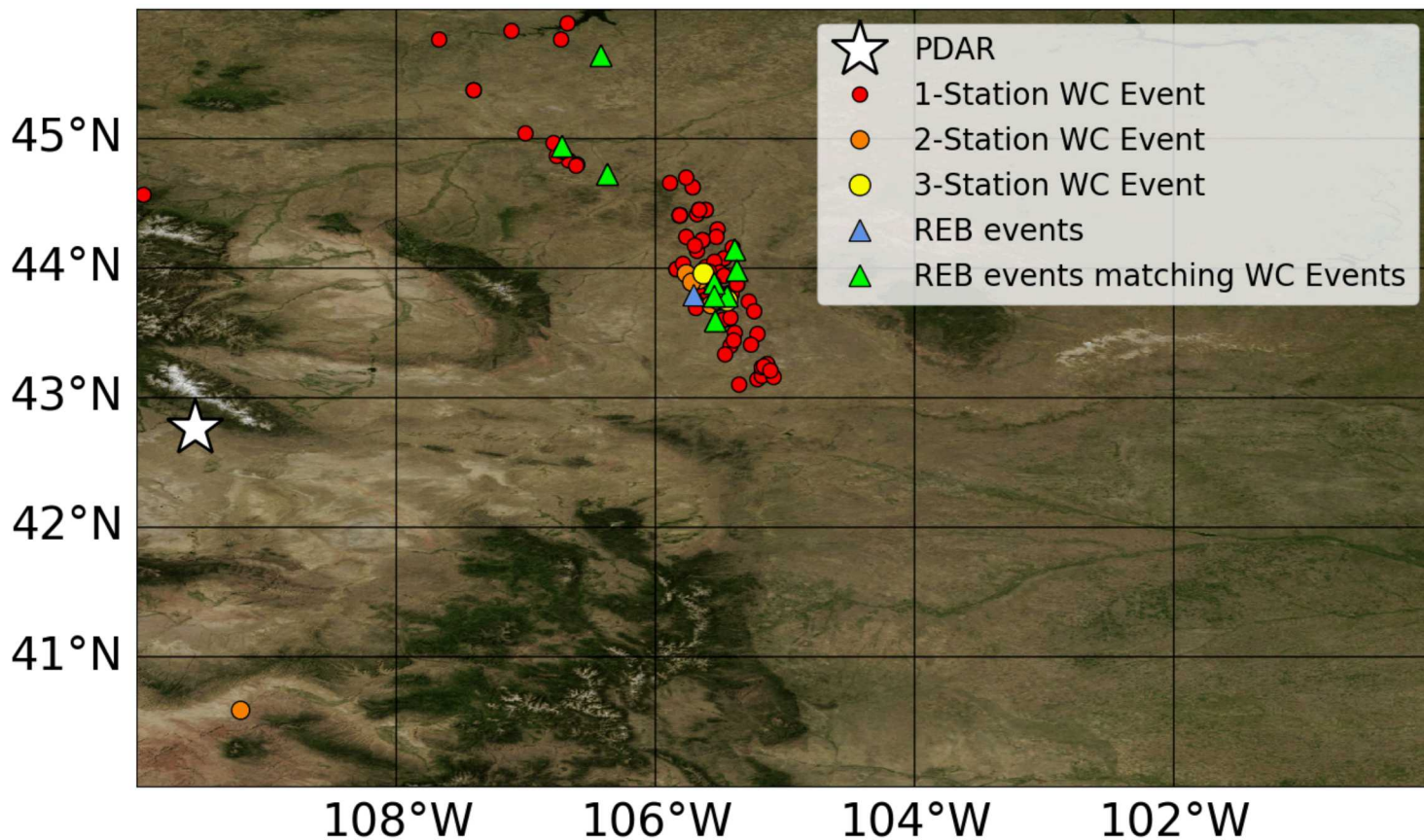
Wyoming Week 2 (8/8/2018 - 8/14/2018) Templates

Map of study area showing 1364 template origin locations by number of stations (1-3) from up to 10 years of REB events.

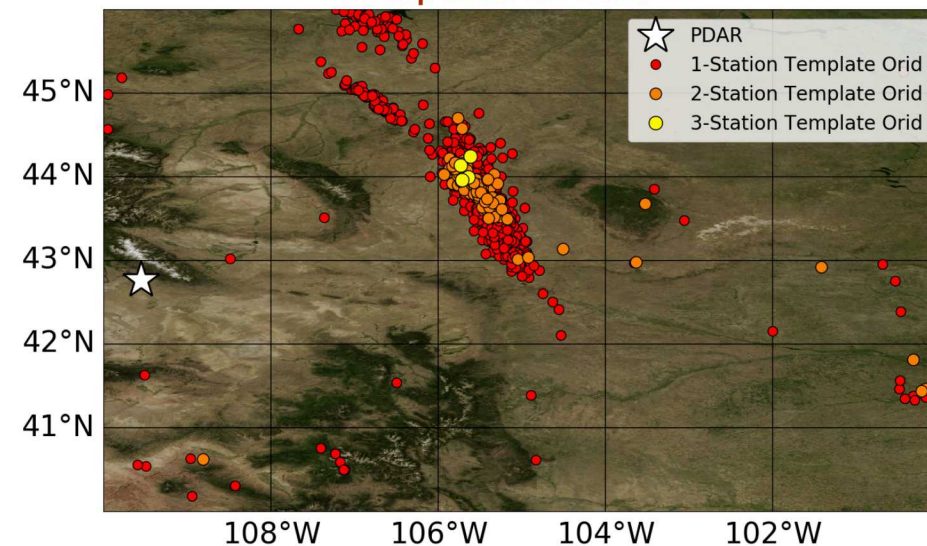


Wyoming Week 2 Waveform Correlation Events

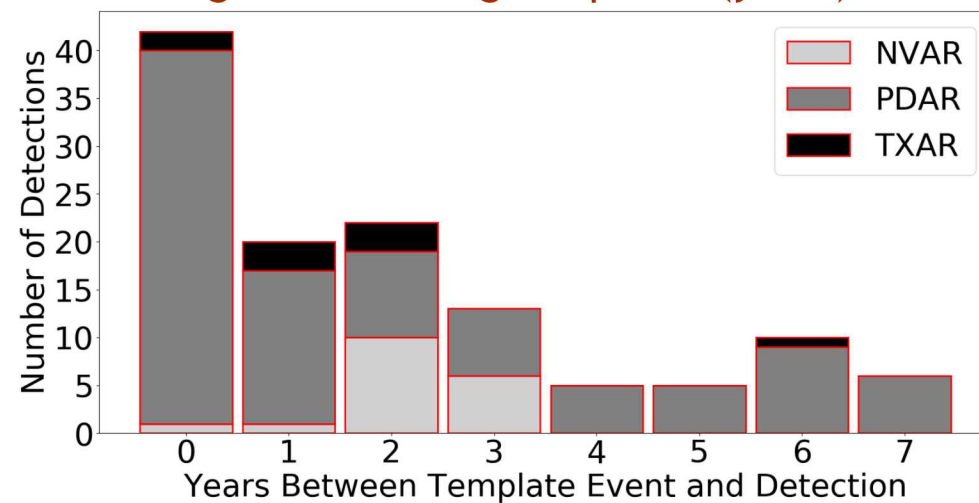
Map showing 112 waveform correlation and 10 REB event locations



Template Events

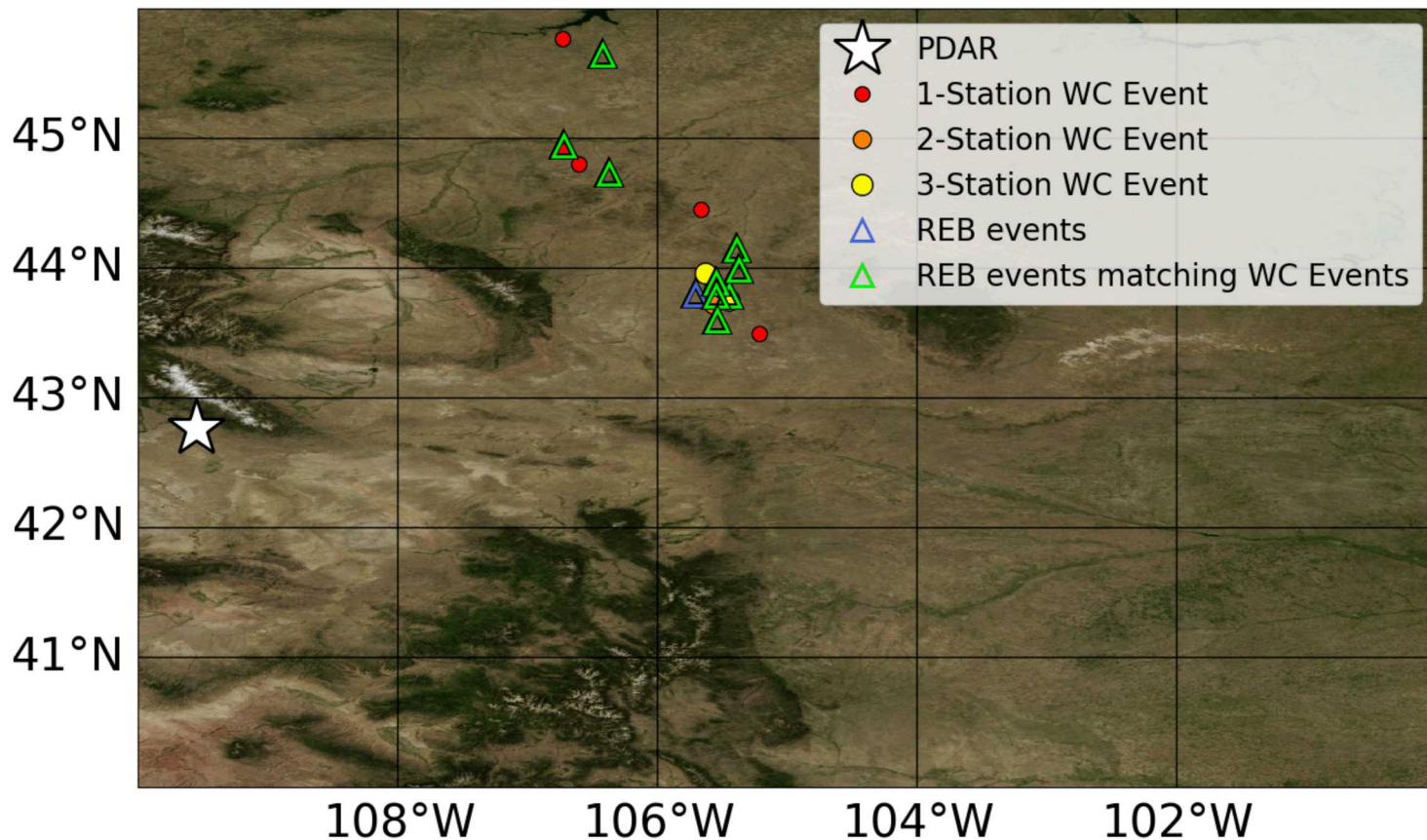


Age of detecting templates (years)

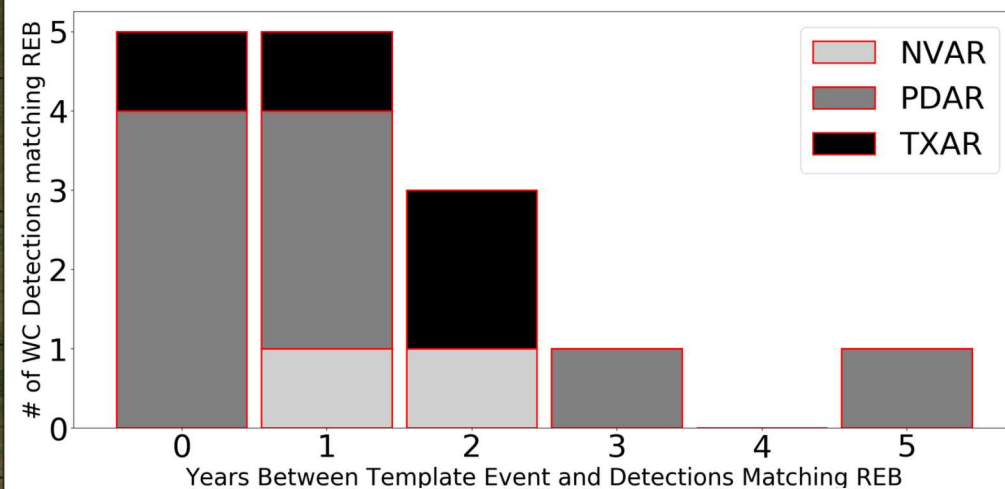


Wyoming Week 2 REB Event Matches

Map showing 10 REB event locations and
9 waveform correlation events within (1° , $\pm 15s$)

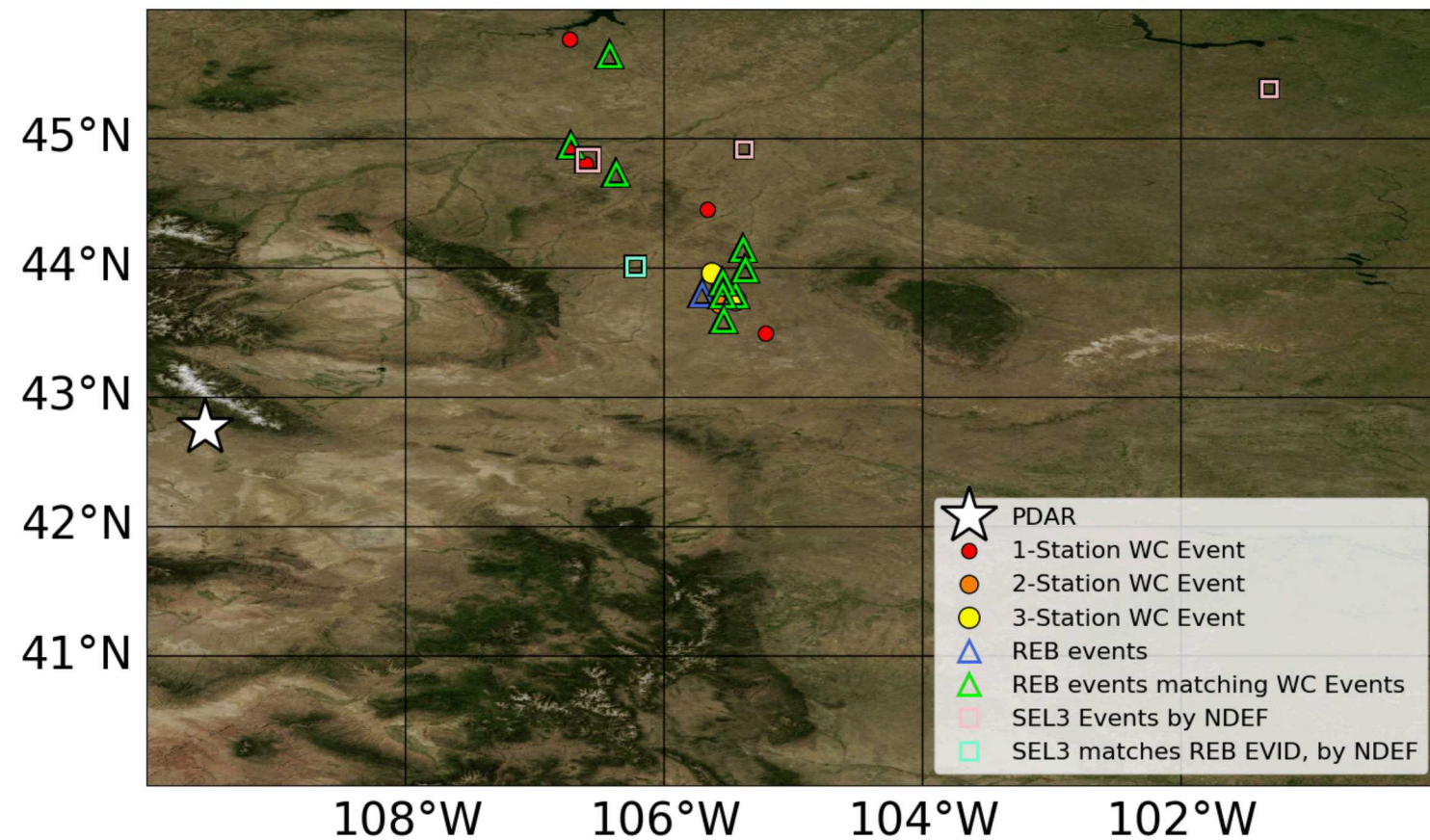


Age of detecting templates matching REB events



Wyoming Week 2 Comparing WC and SEL3 with REB Events

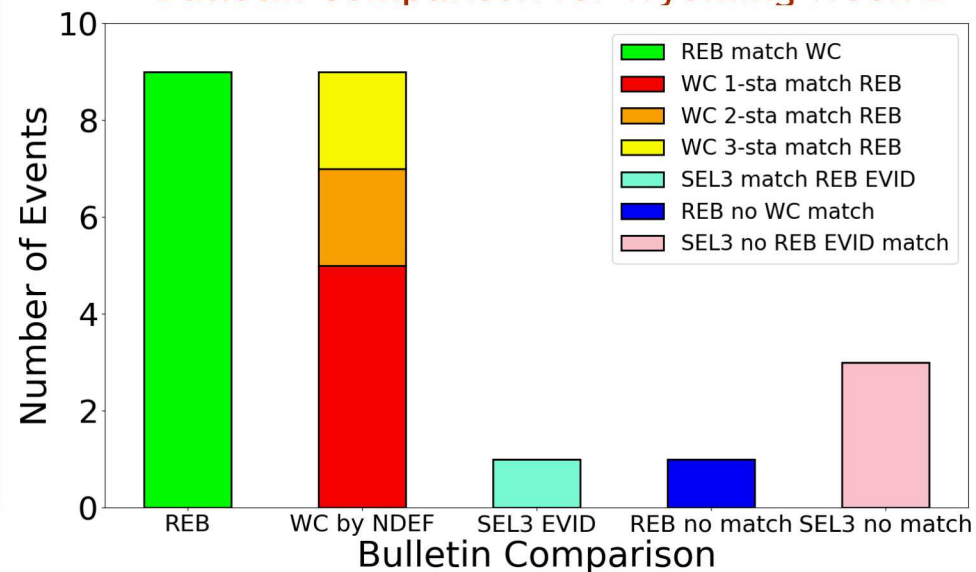
Map showing 10 REB events, 4 SEL3 events, and 9 waveform correlation events within (1° , $\pm 15s$)



Notes for Wyoming Week 2

- Waveform correlation locations are more accurate than SEL3
- Interesting REB event near many templates but not detected by WC.

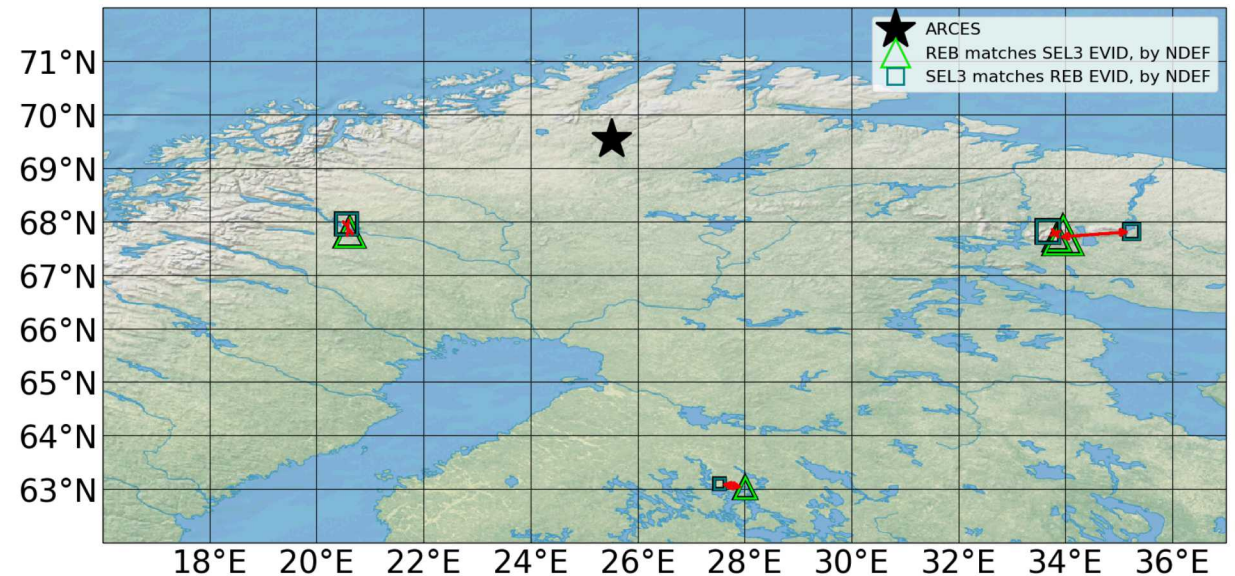
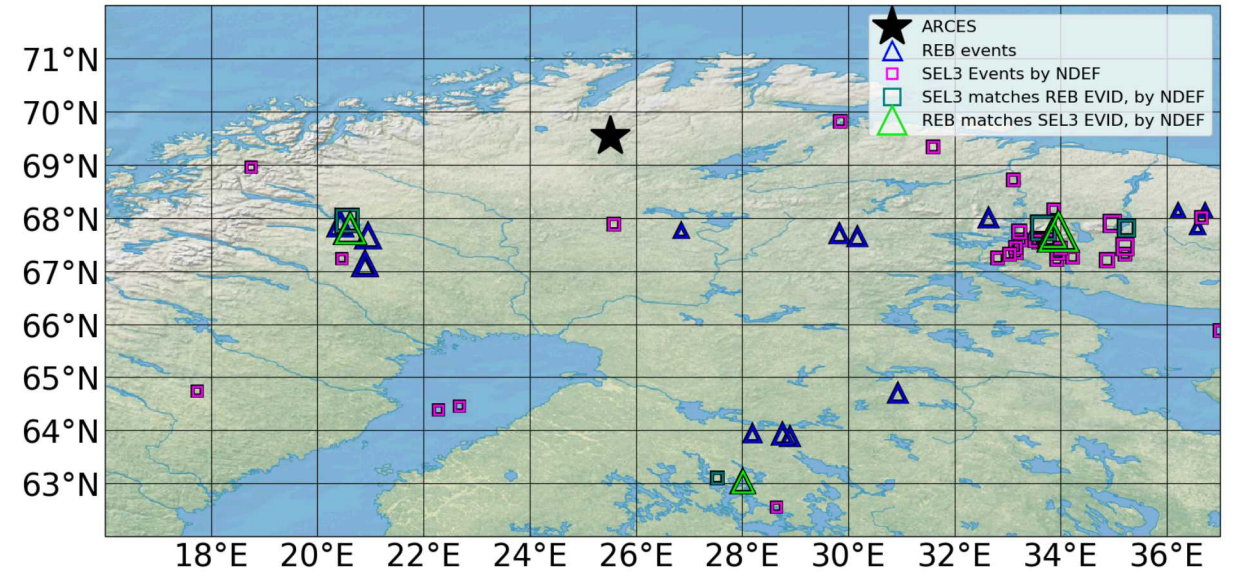
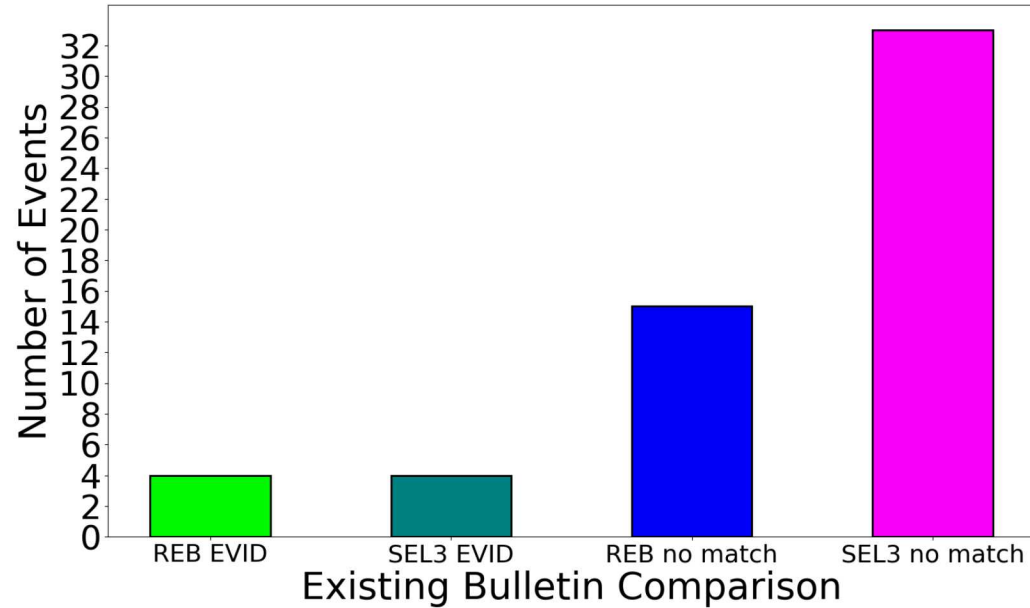
Bulletin Comparison for Wyoming Week 2



Scandinavia Week I (2/12/2018 – 2/18/2018)

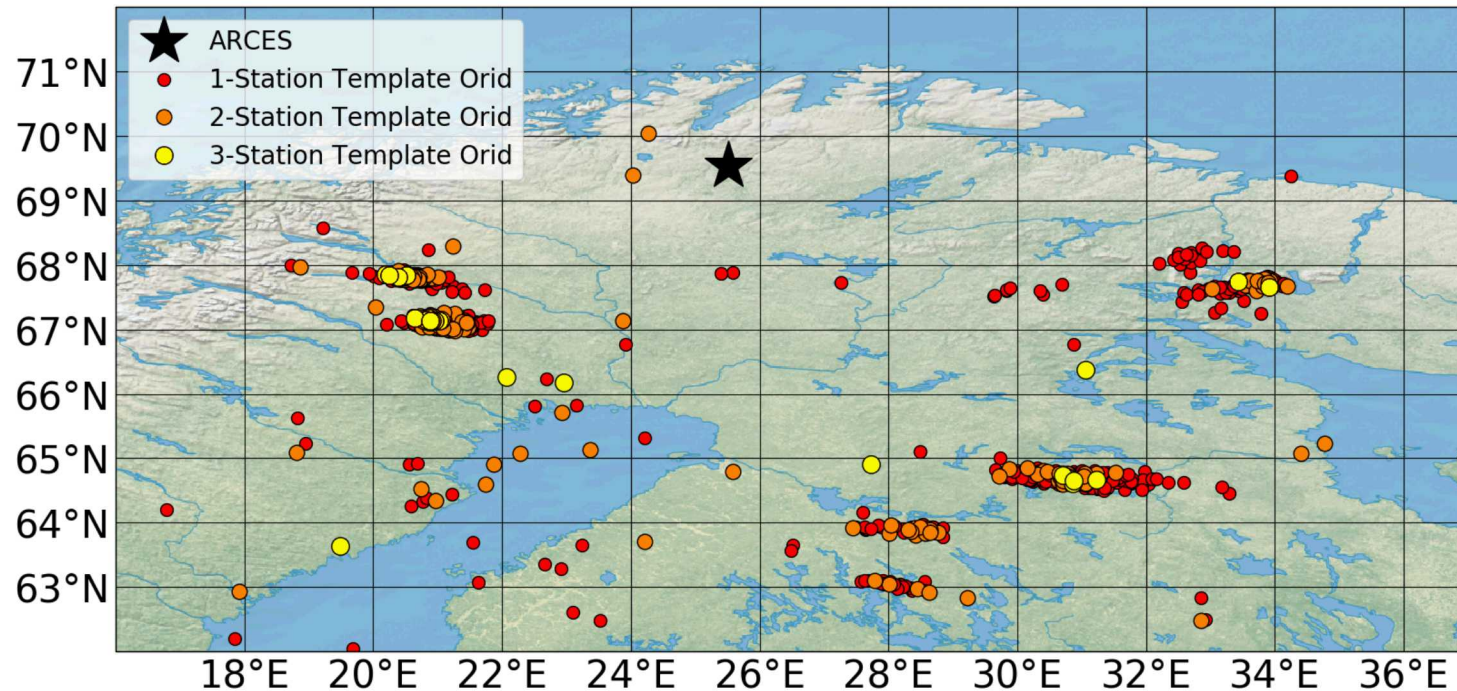
Overview of existing catalogs

- 37 SEL3 Events in region/week
- 4 SEL3 Event EVID = REB Event EVID
- 15 REB Event EVIDs $\neq$ SEL3 Event EVIDs
- 19 REB Events in region/week

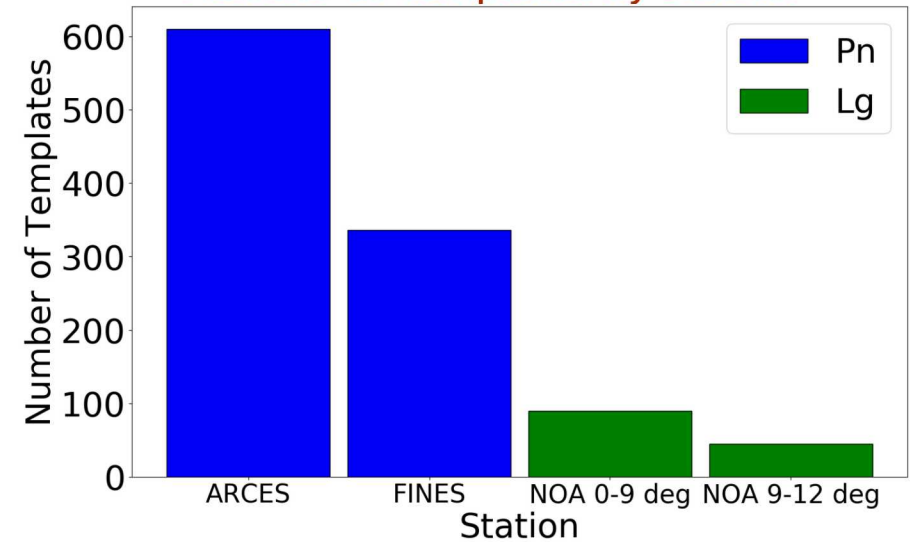


Scandinavia Week I (2/12/2018 - 2/18/2018) Templates

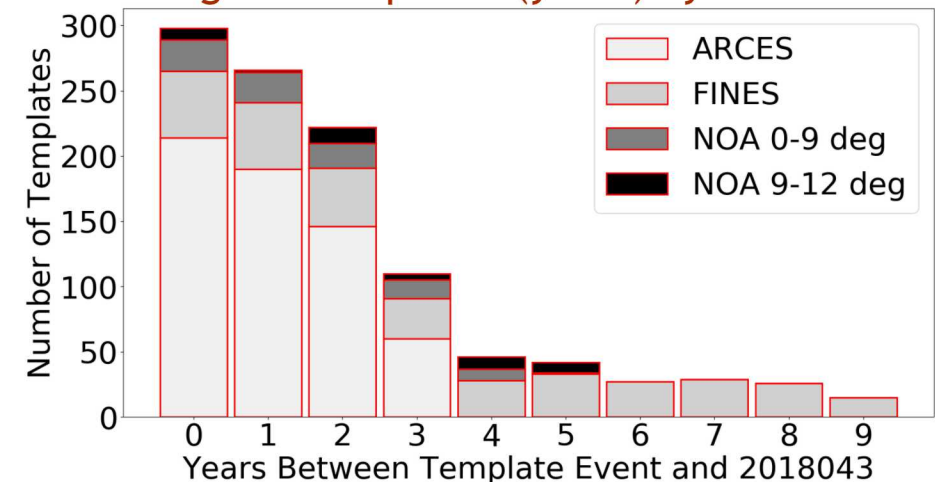
Map of study area showing 970 template origin locations by number of stations (1-3) from up to 10 years of REB events.



Number of templates by station

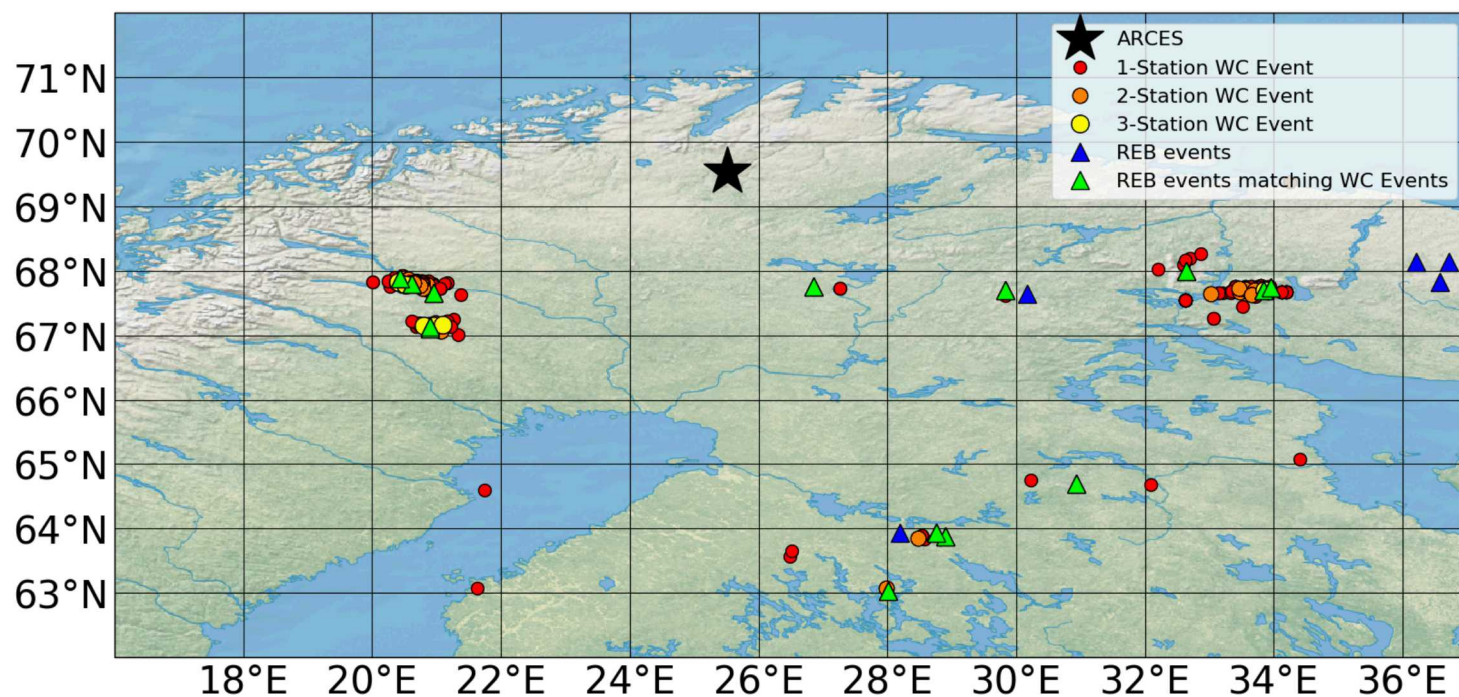


Age of templates (years) by station

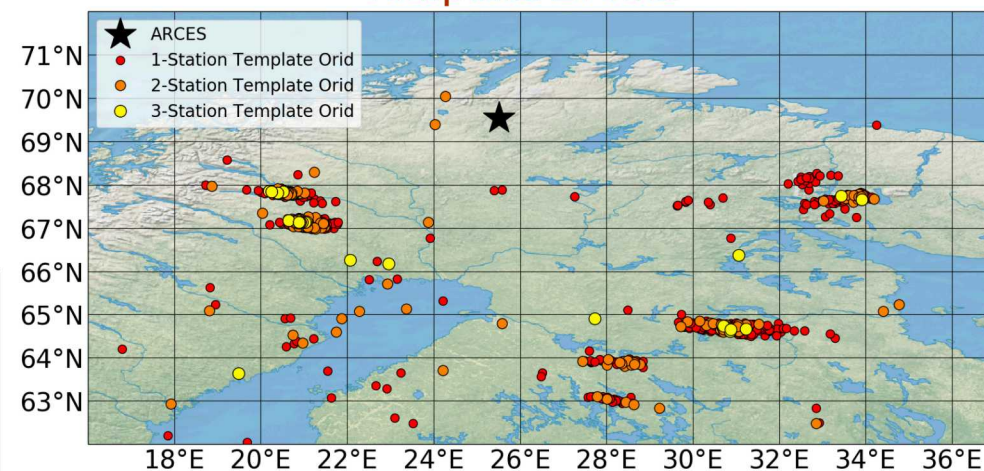


Scandinavia Week I Waveform Correlation Events

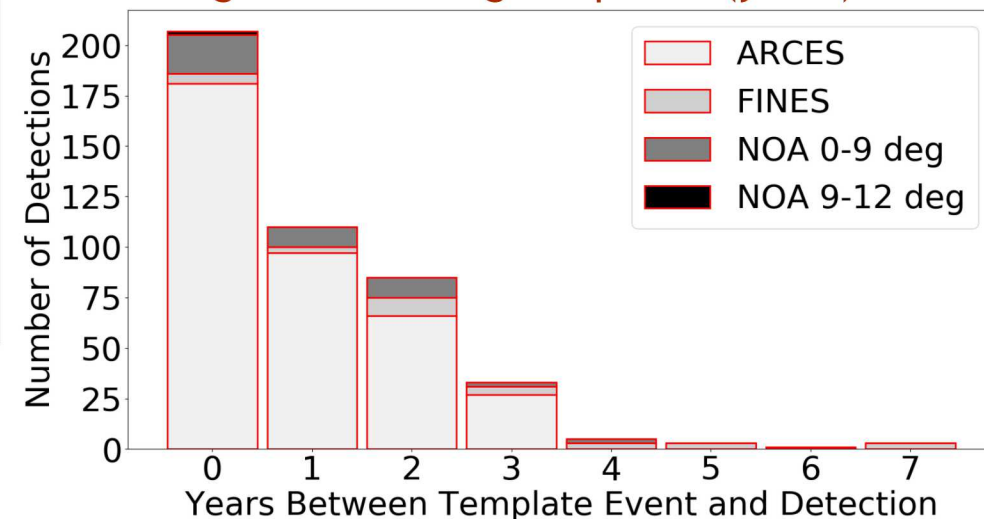
Map showing 390 waveform correlation
and 19 REB event locations.



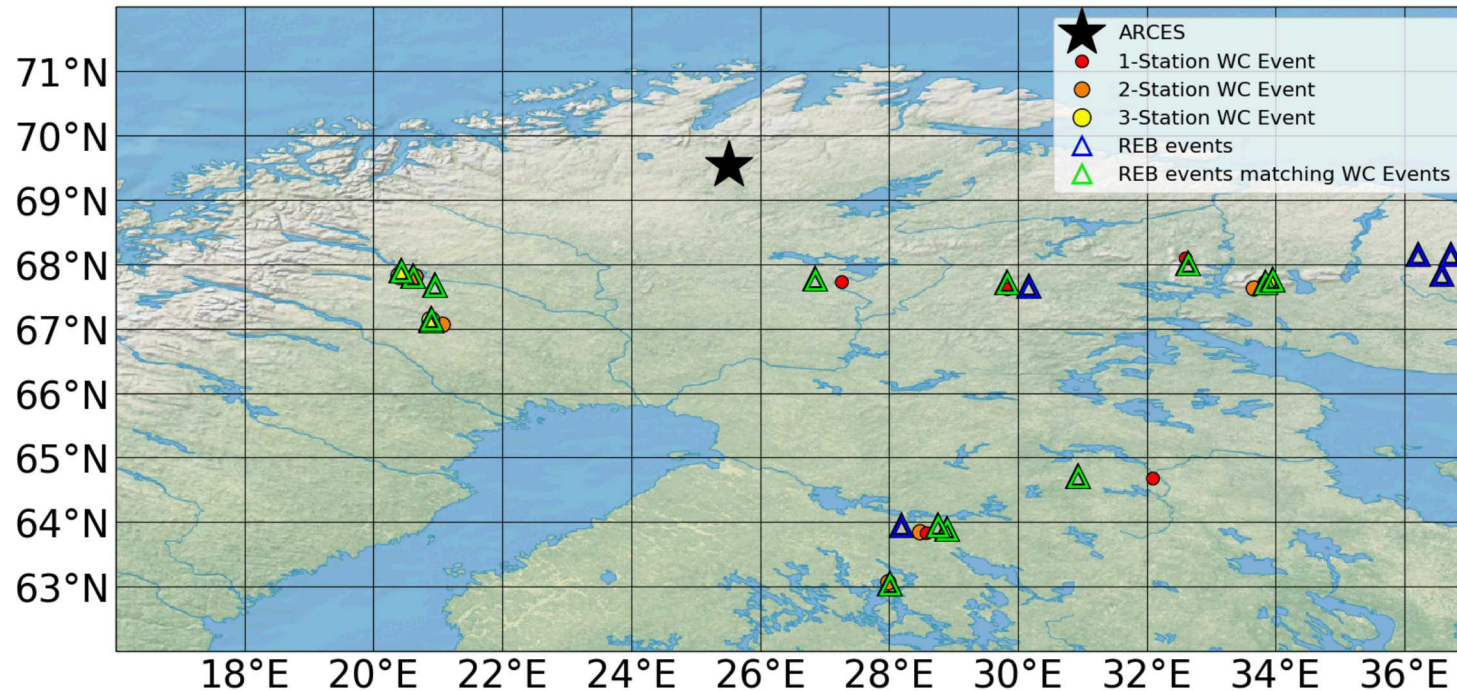
Template Events



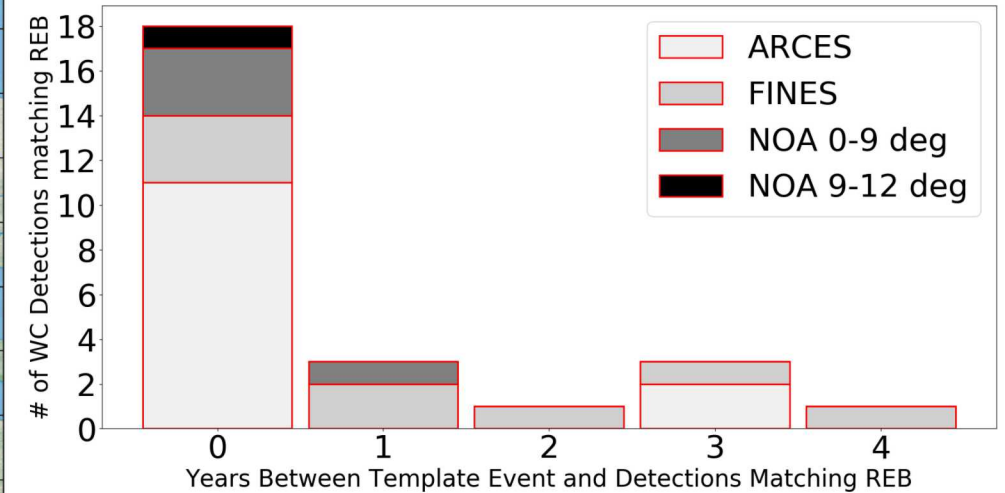
Age of detecting templates (years)



Map showing 19 REB event locations and
14 waveform correlation events within (1° , $\pm 15s$)

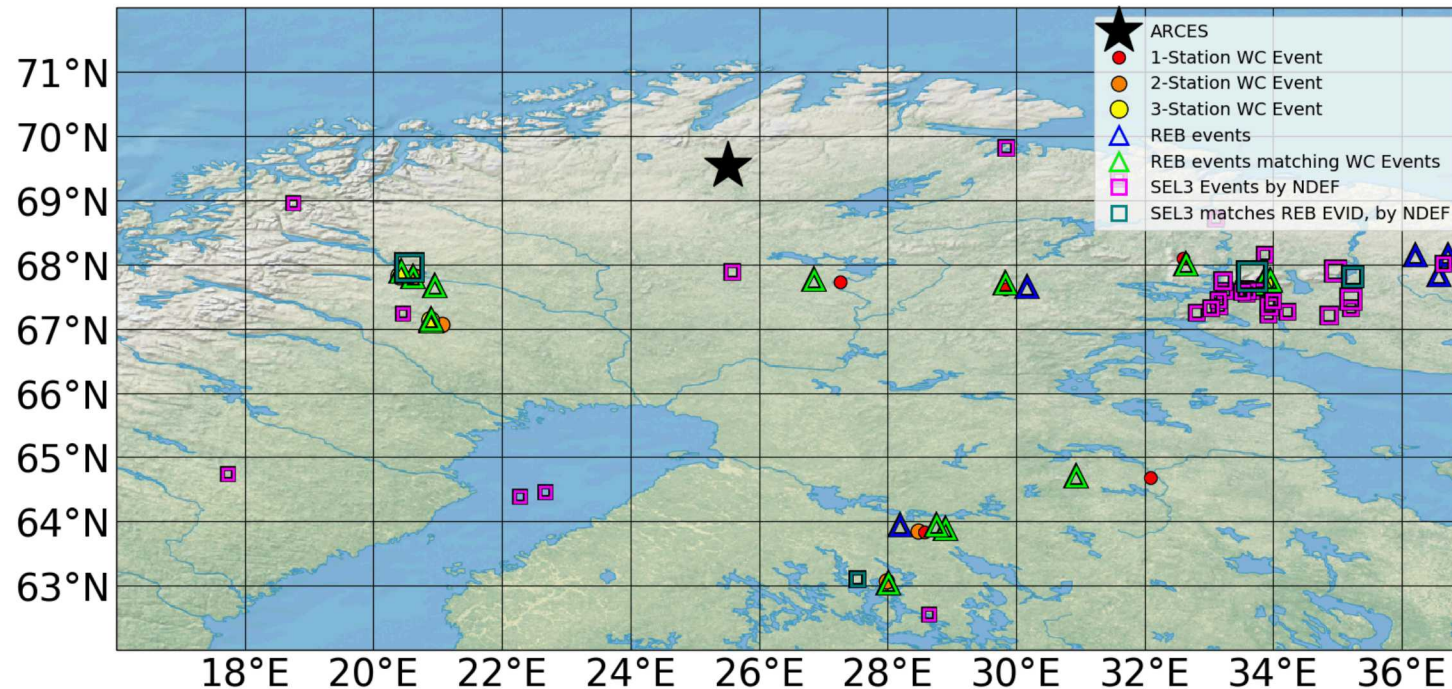


Age of detecting templates matching REB events



Scandinavia Week I Comparing WC and SEL3 with REB Events

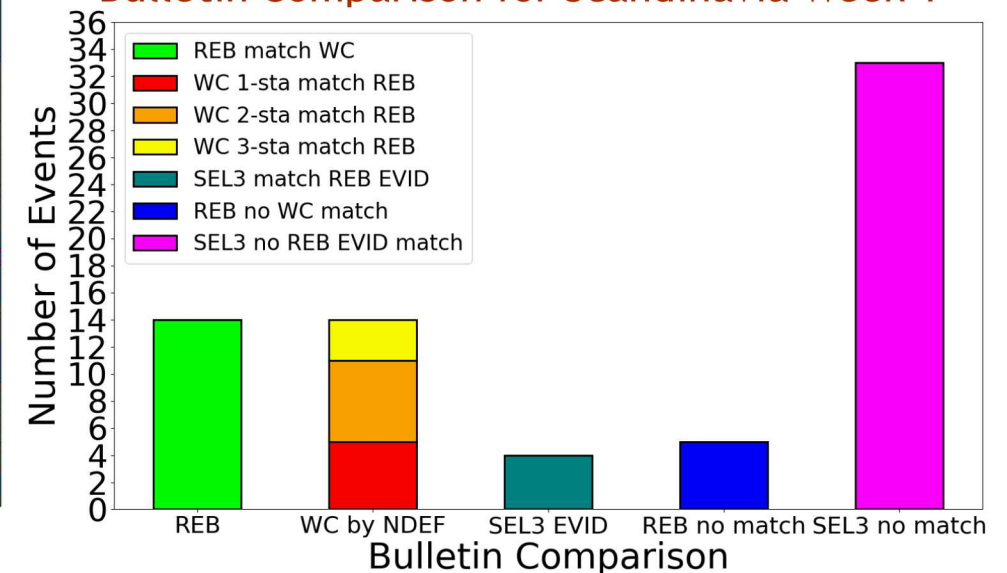
Map showing 19 REB events, 37 SEL3 events, and 14 waveform correlation events within (1° , $\pm 15s$)



Notes for Scandinavia Week 1

- Many events from SEL3 were discarded and/or relocated

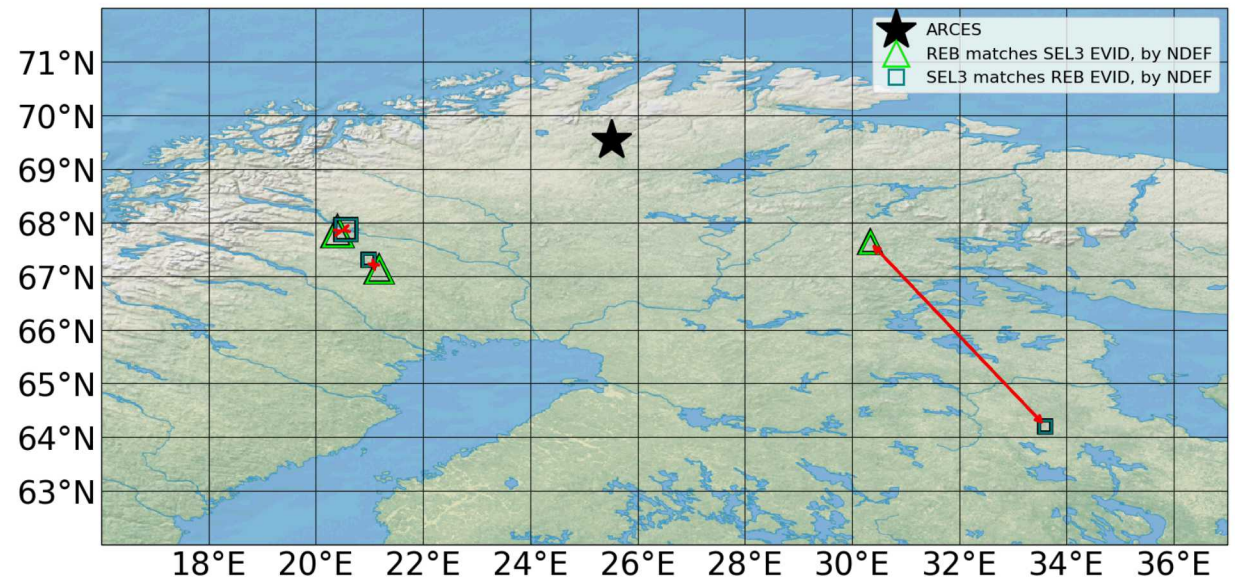
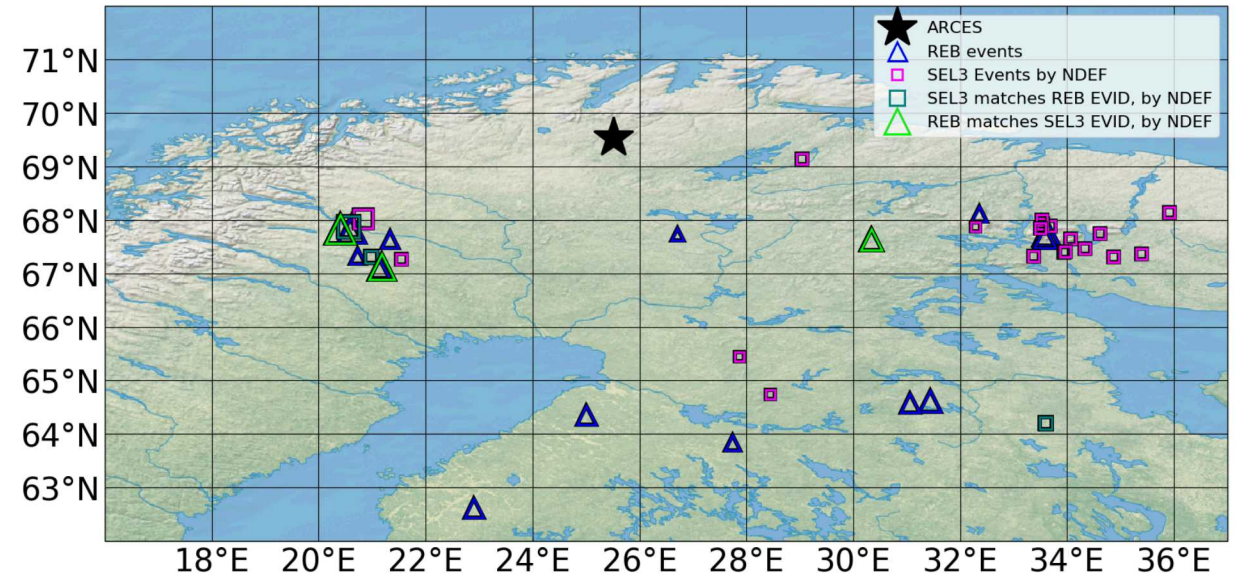
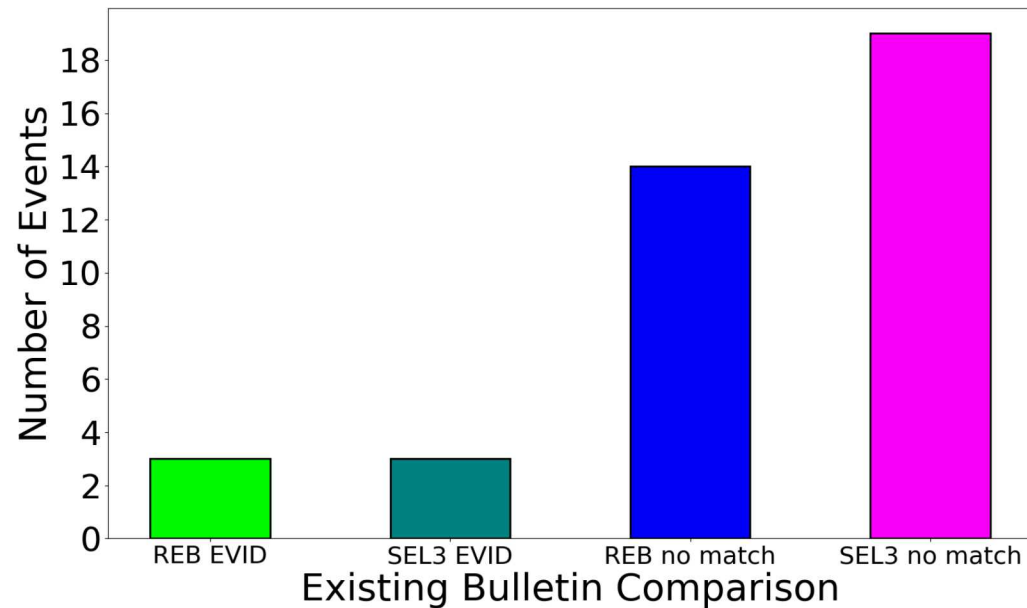
Bulletin Comparison for Scandinavia Week 1



Scandinavia Week 2 (7/6/2018 – 7/12/2018)

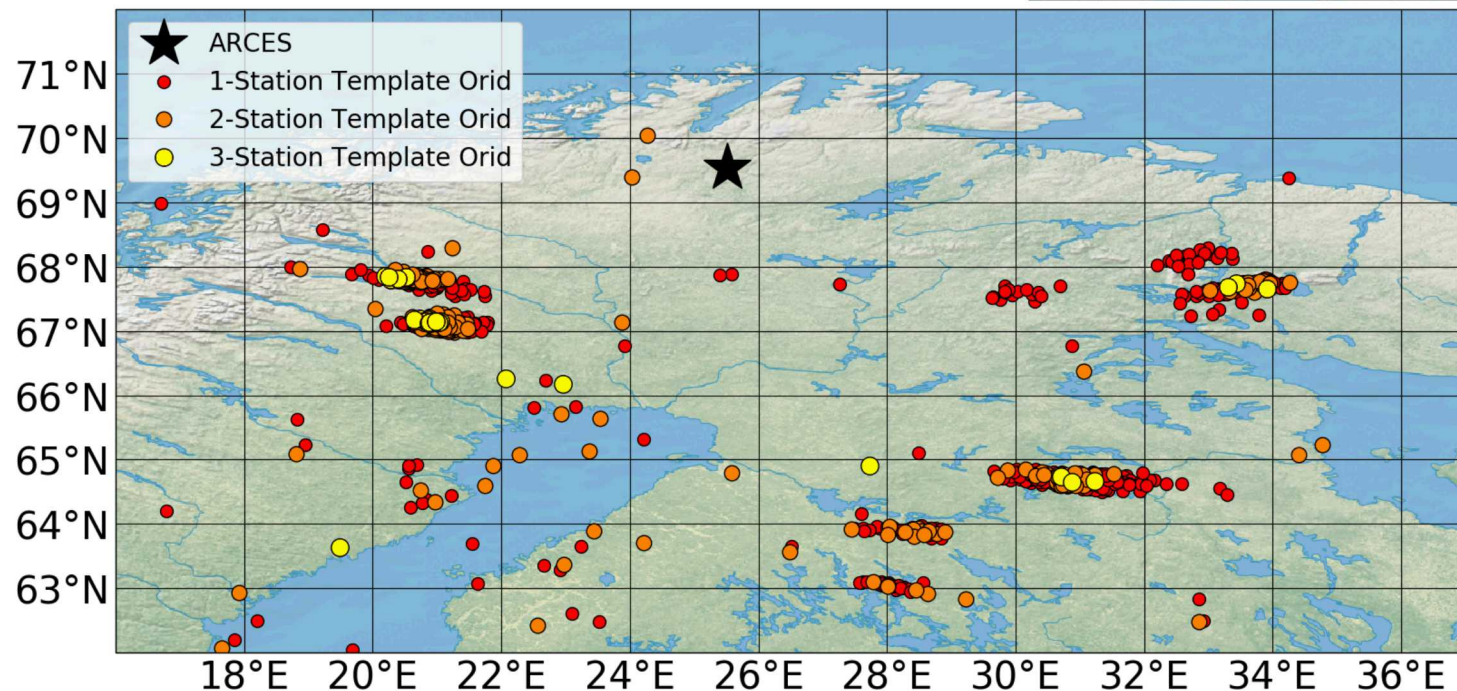
Overview of existing catalogs

- 22 SEL3 Events in region/week
- 3 SEL3 Event EVID = REB Event EVID
- 14 REB Event EVIDs $\neq$ SEL3 Event EVIDs
- 17 REB Events in region/week

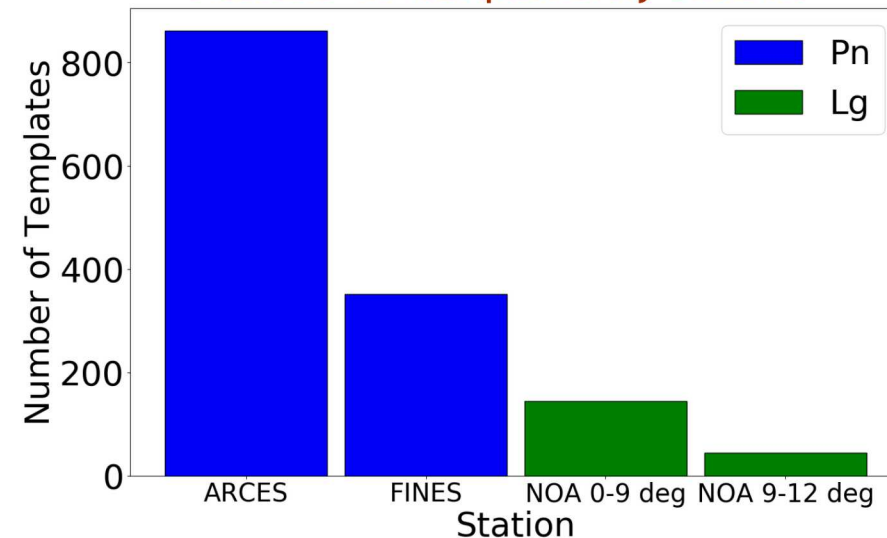


Scandinavia Week 2 (7/06/2018 - 7/12/2018) Templates

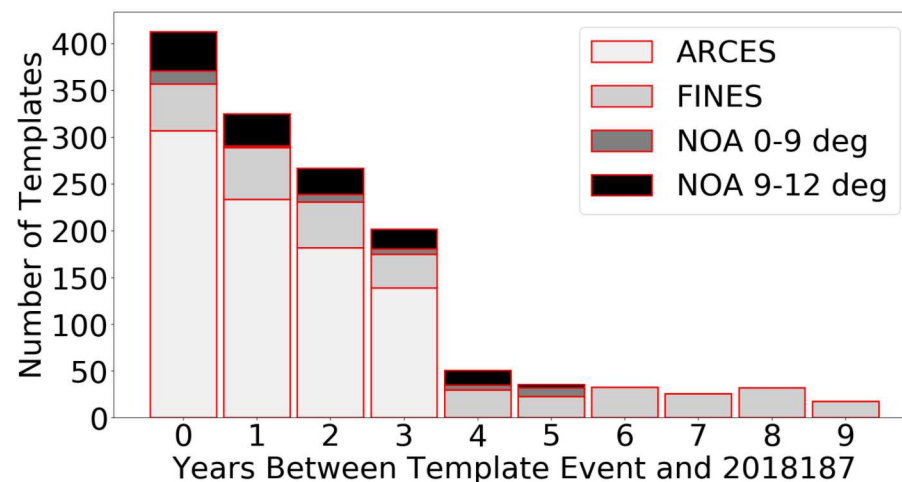
Map of study area showing 1140 template origin locations by number of stations (1-3) from up to 10 years of REB events.



Number of templates by station

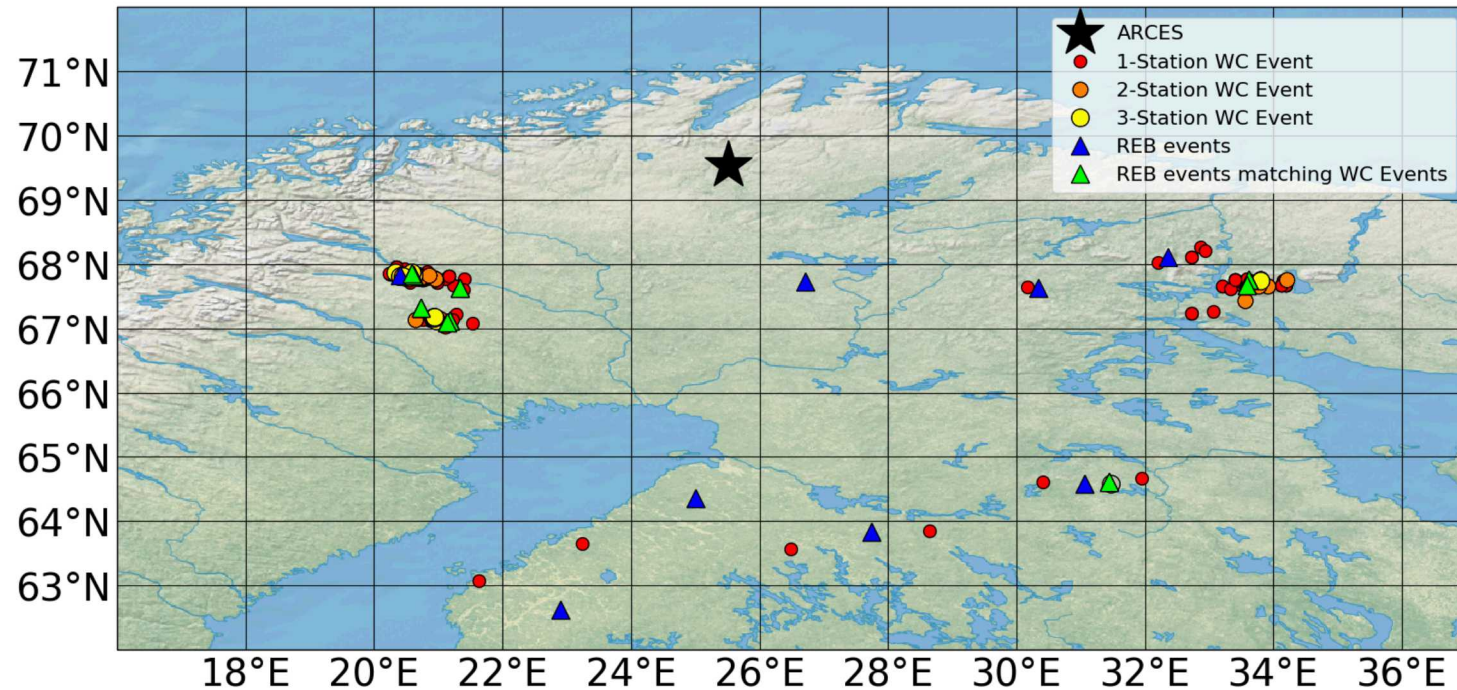


Age of templates (years) by station

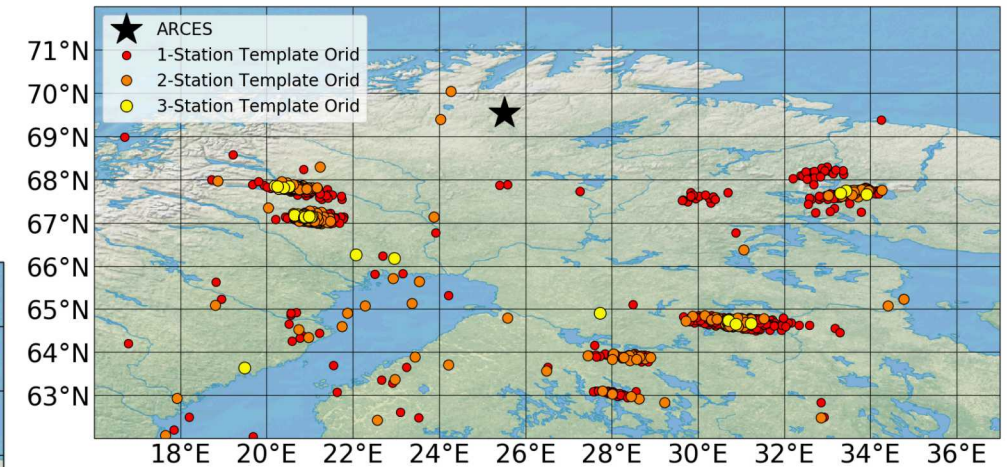


Scandinavia Week 2 Waveform Correlation Events

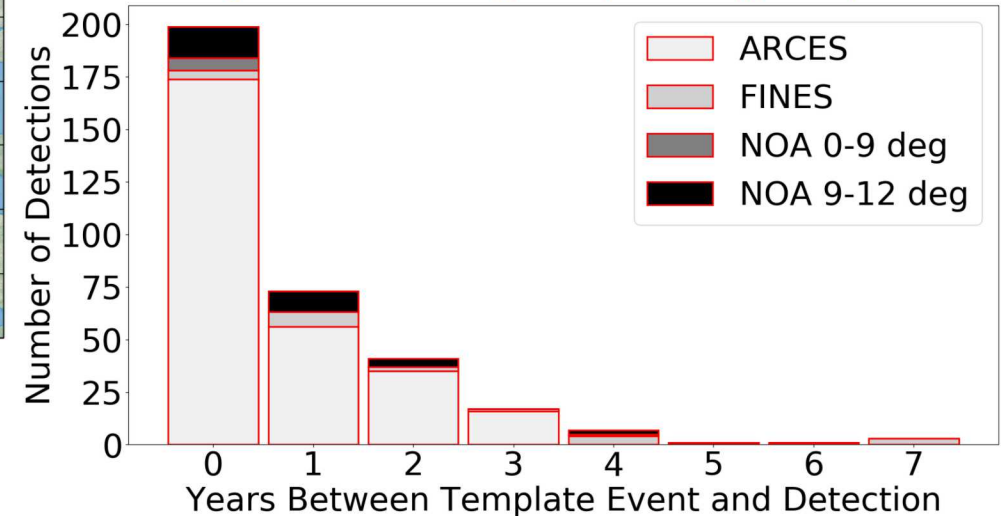
Map showing 291 waveform correlation
and 17 REB event locations.



Template Events

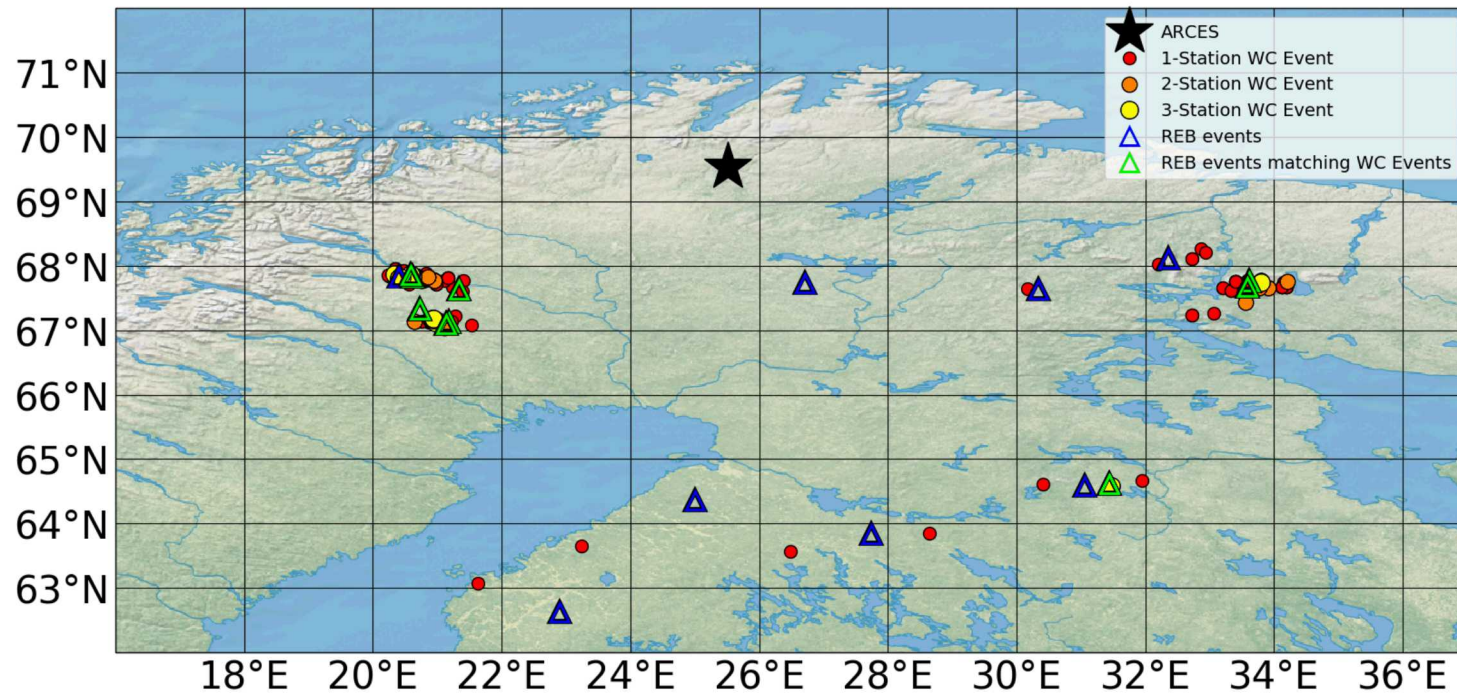


Age of detecting templates (years)

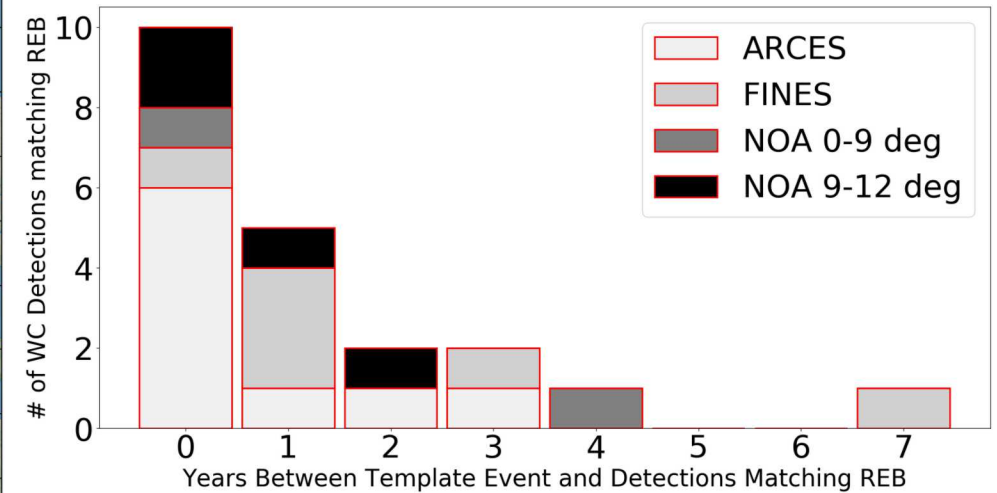


Scandinavia Week 2 REB Event Matches

Map showing 17 REB event locations and
9 waveform correlation events within (1° , $\pm 15s$)

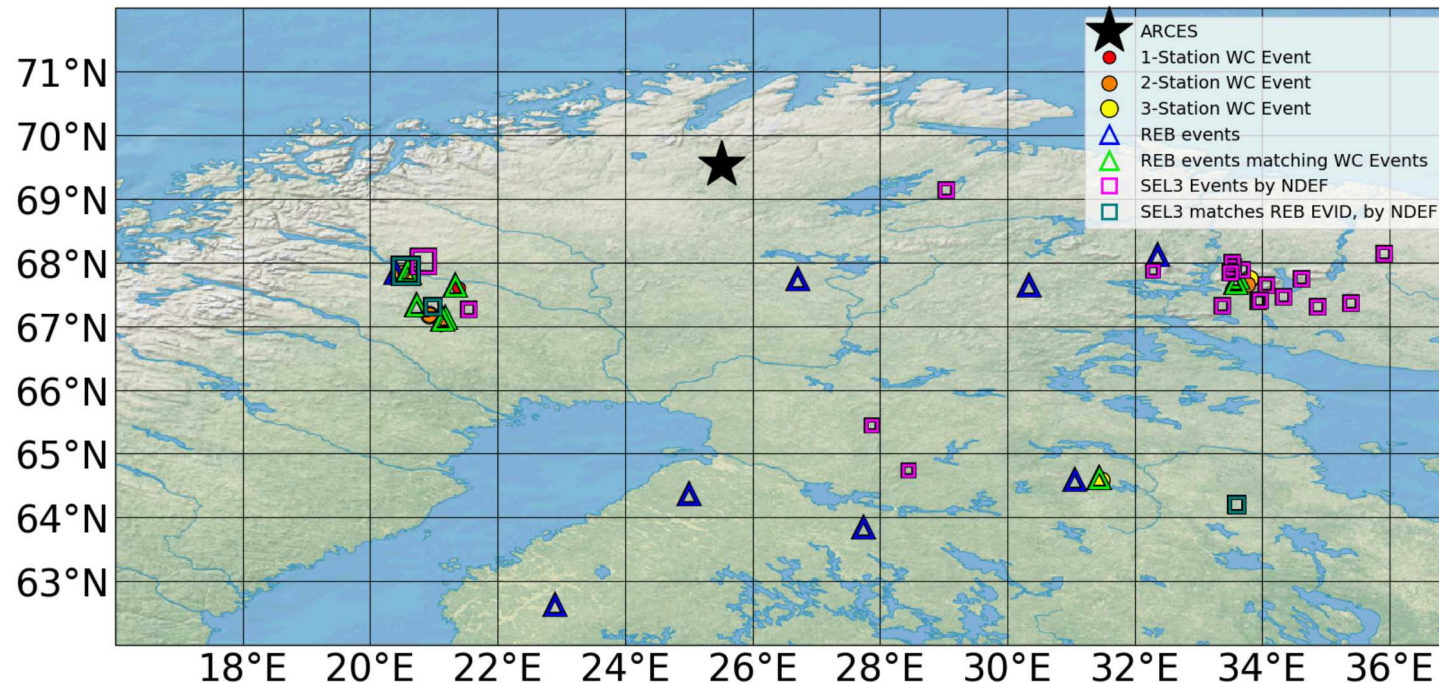


Age of detecting templates matching REB events



Scandinavia Week 2 Comparing WC and SEL3 with REB Events

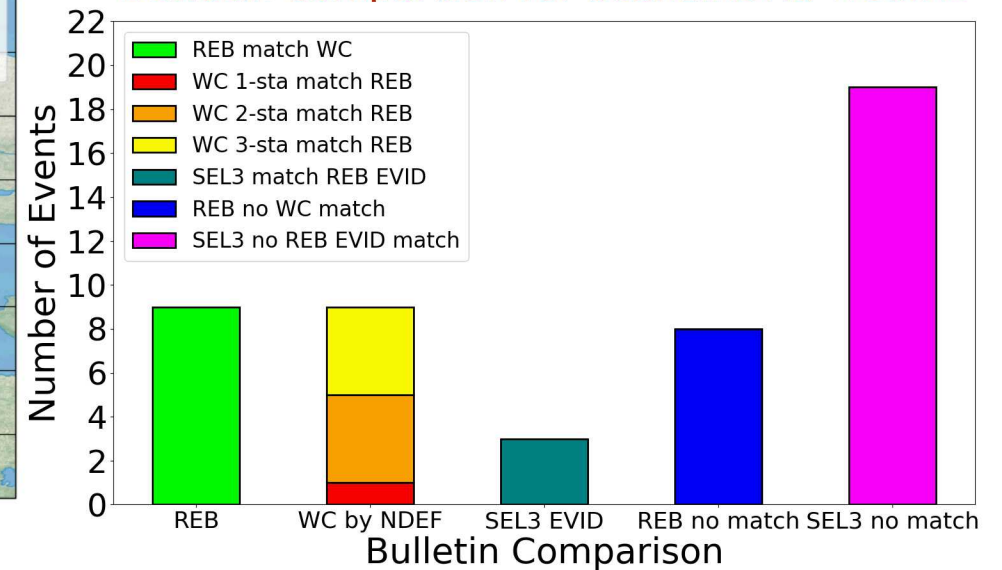
Map showing 17 REB events, 22 SEL3 events, and 9 waveform correlation events within (1° , $\pm 15s$)



Notes for Scandinavia Week 2

- Many events from SEL3 were discarded and/or relocated

Bulletin Comparison for Scandinavia Week 2



- Results indicate that waveform correlation will improve the effectiveness of the IDC pipeline by:
 - detecting many REB events that are currently being missed by SEL3, and
 - providing better locations, which should require less refinement by the analysts.
- Using long duration templates for close stations yields good results.
- Due to the sparseness of the IMS network and the small size of mining explosions, many historical events only have good templates at one station.
 - We allowed single station WC detections to take better advantage of the archive.
 - However, our past work suggests that single station WC detections may include many marginal and/or false events.
 - Careful selection of templates may reduce false events.

Conclusions (continued)

- Waveform correlation finds a large percentage of REB events, but
 - also generates many additional events, which
 - may require analyst effort to review, whether the events are legitimate or not.
- Further investigation is required to screen the WC events to detect the REB events without additional events that are not useful for the analysts.

Thank you for inviting SNL to participate in the PTS Recurring Events study of waveform correlation techniques!