# Investigating the seismicity around the DPRK test site

Ben Dando, Anna Maria Dichiarante, Bettina Goertz-Allmann, Andreas Köhler, Volker Oye

NORSAR, Gunnar Randers Vei 15, N-2007 Kjeller, Norway
ben@norsar.no

NORSAR

INTRODUCTION AND MAIN RESULTS

Using multi-channel correlation detectors at KSRS (PS31) and USRK (PS37) with templates from the DPRK tests, the 2017 collapse and natural/triggered earthquakes, NORSAR has detected almost 200 events around the test site; with activity peaking in 2023 and 2024. Clustering of the events reveal 8 distinct groups (9 including the nuclear tests), two of which can be strongly constrained to a region ~8 km NNW of the test site.

SnT 2025
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Investigating the seismicity around the DPRK test site

Ben Dando, Anna Maria Dichiarante, Bettina Goertz-Allmann, Andreas Köhler, Volker Oye

P3.5-392
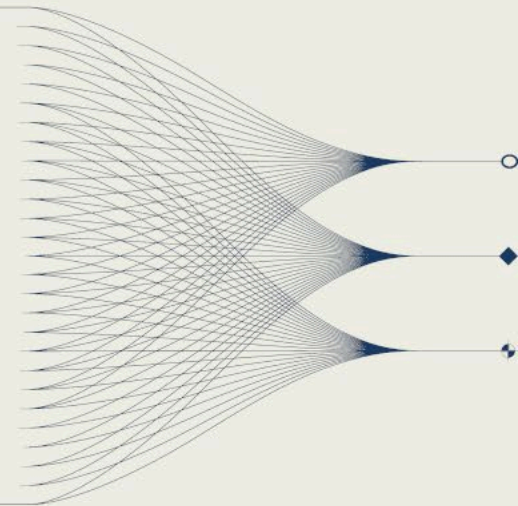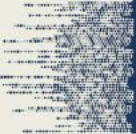
Multi-channel correlation detectors

- Multi-channel correlation detectors at KSRS (PS31, South Korea) and USRK (PS37, Russia) seismic arrays.
- Templates from 5 out of 6 nuclear tests, one collapse event and 11 triggered earthquakes. Total of 31 custom templates (Fig. 1 & 2).
- Correlation detectors follow the approach of Gibbons & Ringdal (2012).
- Multichannel correlation statistic calculated by averaging per-channel traces C|C|.
- Threshold set using a detection statistic SNR (DSSNR): C(t)/σ, where σ is the S.D. of the statistic over a longer time window (15-30 min). Triggers require 2 templates to have DSSNR ≥ 30, and for an f-k test to indicate |s| ≤ 0.01 s km⁻¹ and the relative beam power (beam energy divided by the mean single-trace energy) is >0.2.
- All templates have been run back from 2006 data to present.
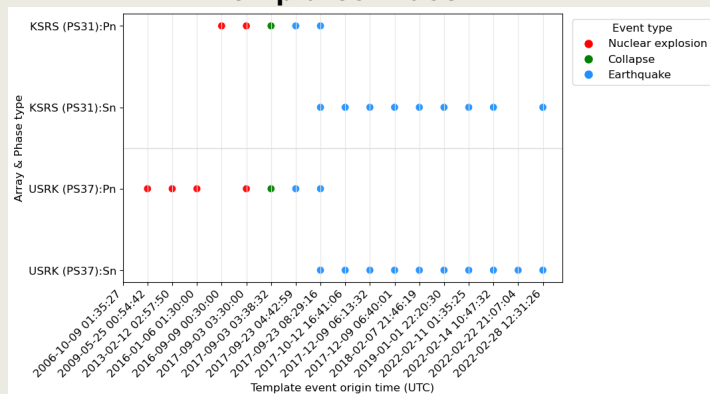
Templates in use

Figure 1
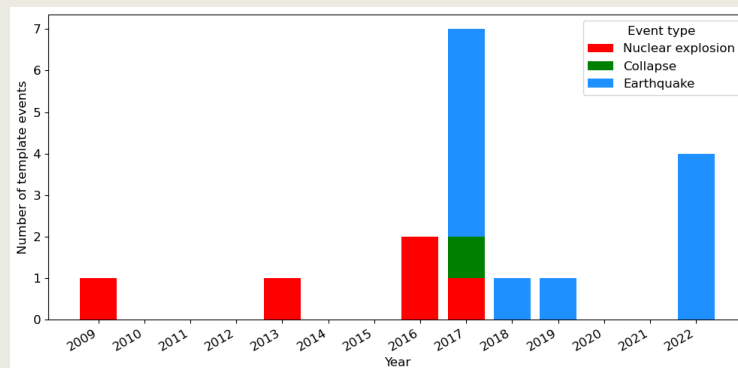
Timeline of event templates

Figure 2

Performance of correlation detectors

- Detectors have identified 198 events (see next slide) triggered by 895 individual detections across the 31 templates.
- The best and worst performing templates are shown in Figs 3-5.
- Natural/triggered events on 23/9/2017 (Mb 3.1), 11/2/2022 (Mb 3.7) and 01/01/2019 (Mb 3.0) have triggered the most detections (Fig. 3 & 4).
- The post-nuclear test collapse in 03/09/207 (Mb 4.0) has triggered the fewest detections (Fig. 3 & 4).
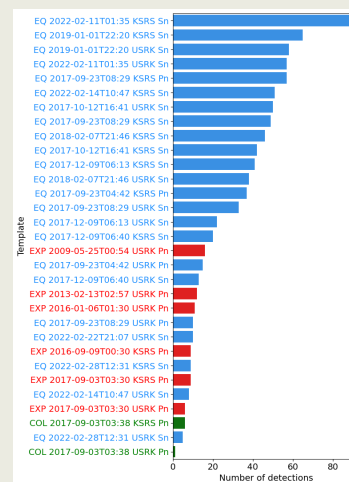
Template performance

Figure 3

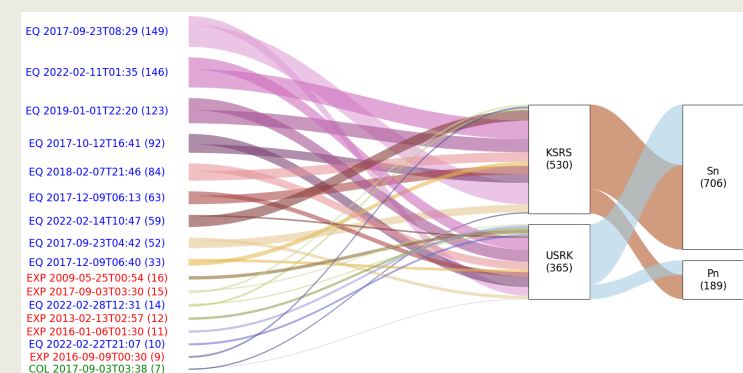## Detections per event/array/phase

Figure 4

- KSRS outperforms USRK detections despite fewer templates (Fig. 4).
- Significant increase in detections after DPRK 6 (2017) and again in 2023 (Fig. 5).
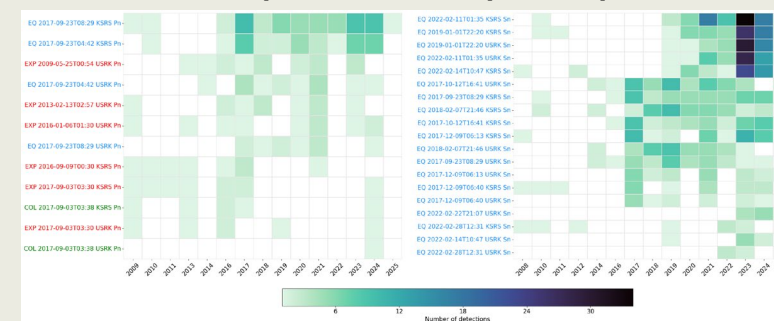
Heatmap of detections per template

Figure 5

NORSAR

SnT 2025
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

8 SEPTEMBER
ONLINE DAY
9 TO 12 SEPTEMBER
AT HOFBURG PALACE, VIENNA & ONLINE

Investigating the seismicity around the DPRK test site

P3.5-392

Ben Dando, Anna Maria Dichiarante, Bettina Goertz-Allmann, Andreas Köhler, Volker Oye

Event detection and clustering

- 198 events detected based on the strict triggering thresholds (DSSNR>30 on two templates) (Fig. 6)
- In comparison: 109 LEB (from CTBTO's IDC) events within 50 km of the test-site.
- 114 events (58%) only detected by NORSAR detectors (Mb 1.8-3.1)
- 84 events match (42%) detected by both NORSAR detectors and LEB.
- 25 LEB events missed by the NORSAR detectors (although detected at lower thresholds) (Mb 2.1-3.3)
- Activity peaked in 2023 and 2024 with 48 and 33 events respectively.
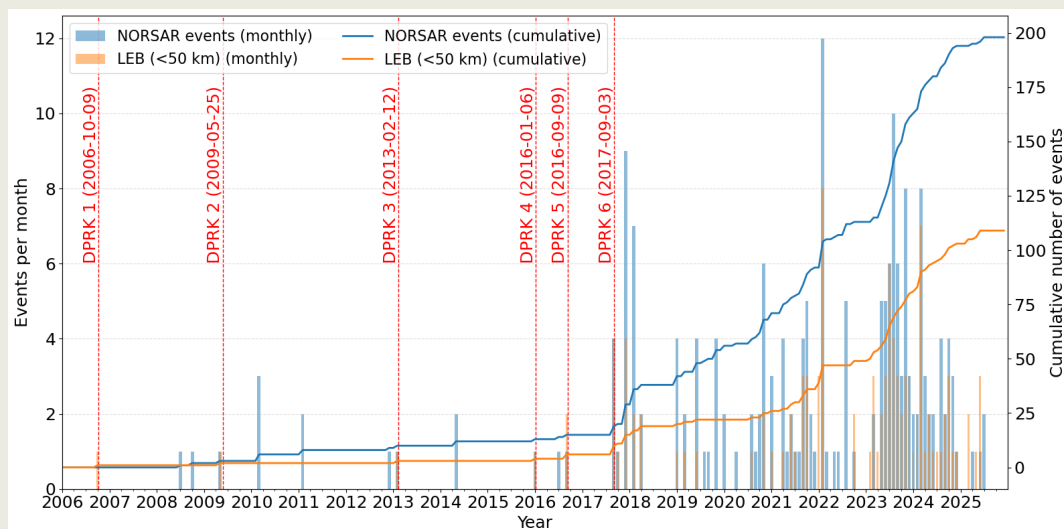- 2025 has had minimal activity.

- All 223 events (including those detected by the LEB) have been cross-correlated across all KSRS and USRK array elements.
- Mean cross-correlation (between USRK and KSRS) shown in Figs. 7 & 8.
- Events that don't correlate well with any other event (i.e. if C<0.4) have been removed: 141 events remaining (e.g. DPRK 1 & collapse event have both been removed).
- 8 distinct clusters (9 including nuclear tests) are clearly formed (Fig. 8).
- Additional sub-clusters visible within cluster 8.
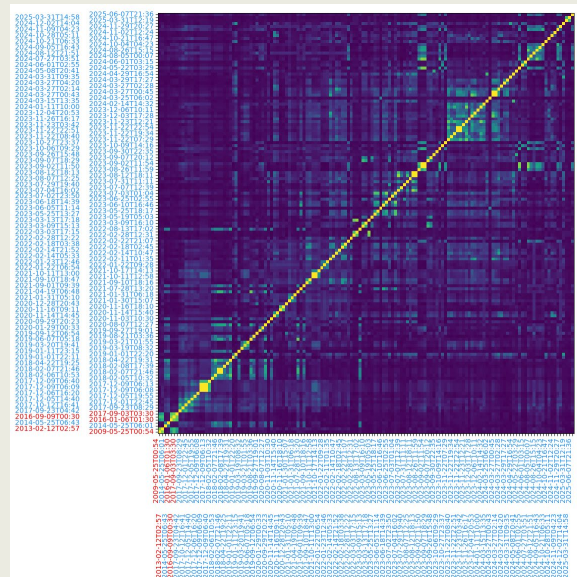
Correlation matrix by time

Correlation matrix clustered

Figure 7

Figure 8

Timeline of events detected

Figure 6

NORSAR

SnT 2025
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE

Investigating the seismicity around the DPRK test site

Ben Dando, Anna Maria Dichiarante, Bettina Goertz-Allmann, Andreas Köhler, Volker Oye

P3.5-392

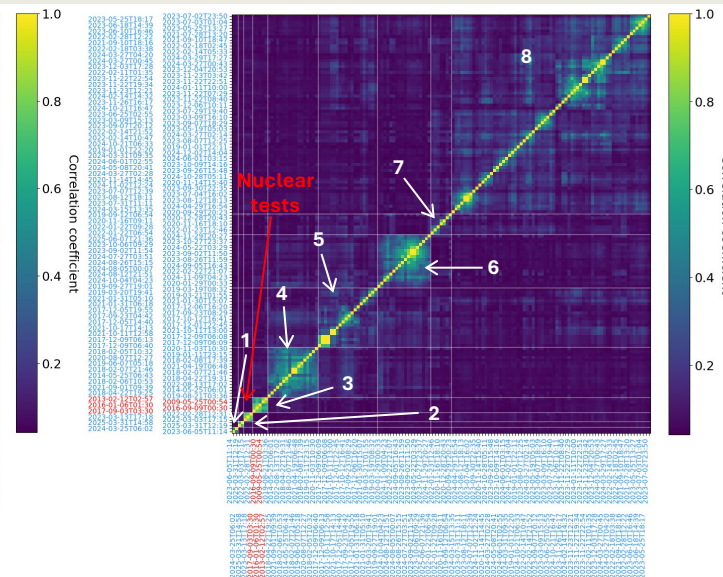## Event clusters, magnitudes & P/S ratios

- Clusters 4 and 5 are most active after the 2017 nuclear test, but have been inactive since 2022.
- The largest cluster (cluster 8) started in 2019 but most activity occurred in 2023 and 2024 with 33 and 19 events respectively.
- Magnitudes have typically been between M2-3, with M3.7 events on 11/2/2022 and 03/07/2023 (both cluster 8).
- P/S ratios at USRK for the five largest magnitude natural triggered events are shown in Fig. 10 together with the six nuclear tests. Clear separation between the earthquakes and tests for all calculated frequency bands.
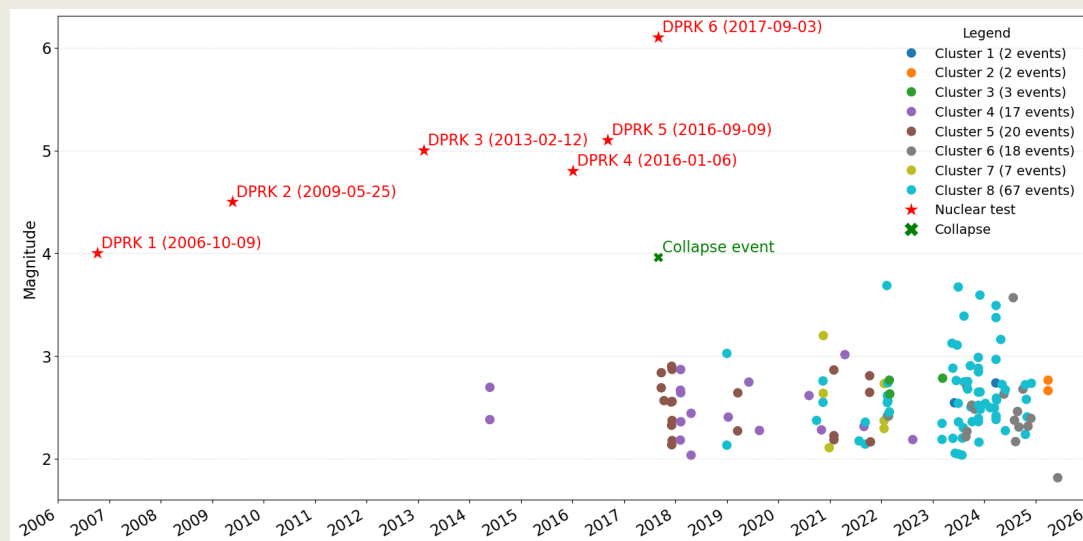
P/S ratio comparison

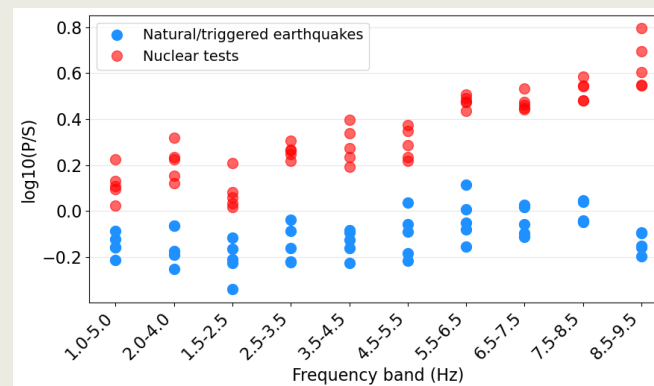*Figure 10*

Map of known cluster locations
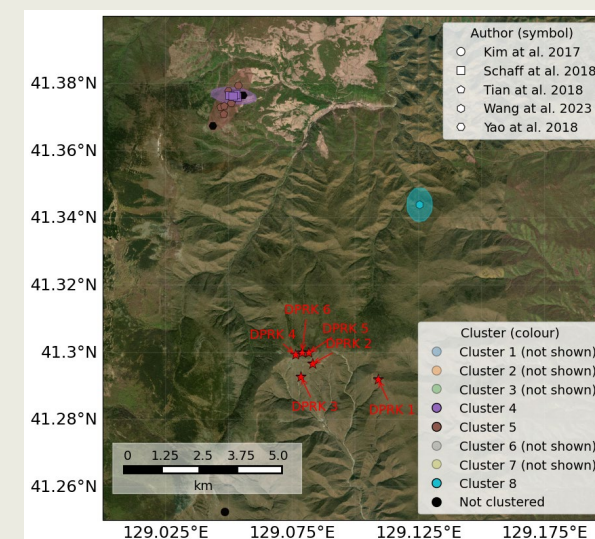

Figure 11

Timeline of event clusters

Figure 9

Constraining cluster locations

- At least 20 seismic events have been precisely located using relative location methods using non-public regional stations (Kim et al. 2017, Schaff et al. 2018, Tian et al. 2018, Yao et al. 2018, Wang et al. 2023) (Fig. 11).
- These 20 events can be regarded as 'control points' for our detections.
- The events belong to 3 clusters (clusters 4, 5 and 8) providing some confidence in the location of events in these clusters.
- Clusters 4 and 5 locate approximately 8 km NNW of the test site.
- Cluster 8 locates approximate 6 km NE of test site (but only one 'control point').
- The location of clusters 1, 2, 3, 6 and 7 are not yet established.
- The 2017 has likely caused significant long lasting stress changes in the region around the test site. As such, seismicity continues to be triggered.

NORSAR