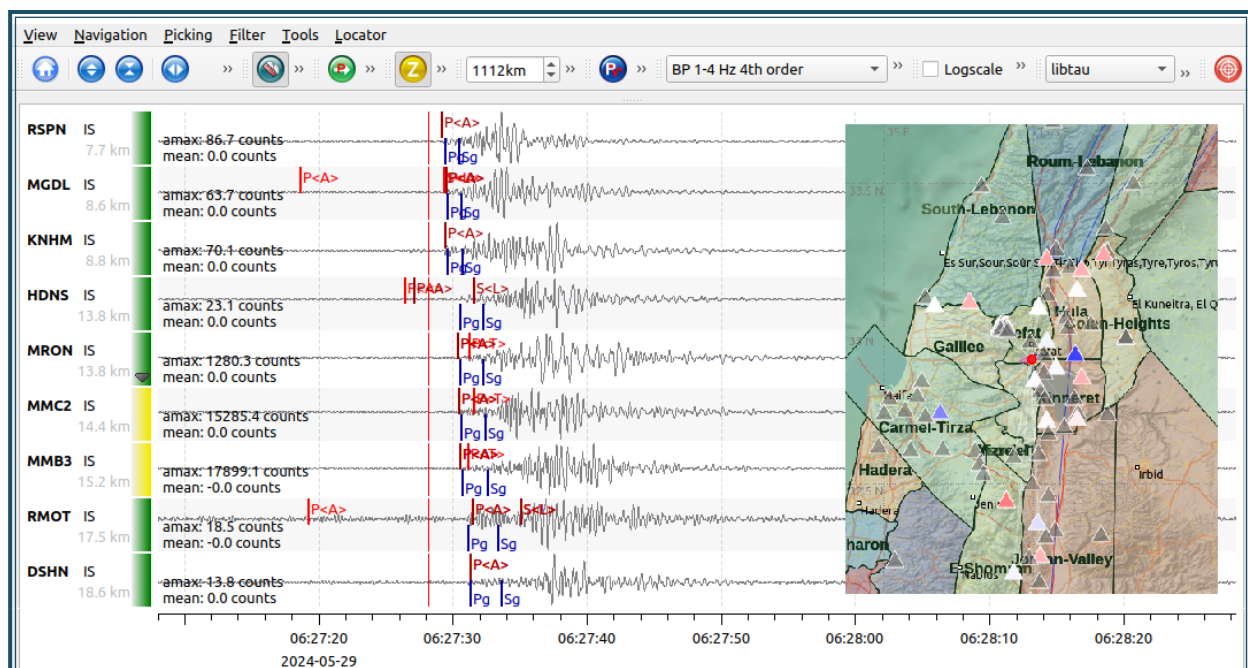




Ministry of Energy
Geological Survey of Israel

Automatic detection of local seismic events in Israel

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Front Picture:

Example of the automatic detection of an event near the Sea of Galilee with the SeisComP software: Seismic phases were automatically picked (red bars) with great precision compared to theoretical predictions (blue bars), resulting in a very accurate event location as seen by the barely visible error ellipse surrounding the event location (red dot in the inset map).

Abstract

At the end of 2022, the [Geological Survey of Israel's Seismological Division](#) upgraded all of its seismic data processing systems to [gempa's SeisComP](#) software package ([GFZ & gempa, 2008](#)). Here, we present the design and implementation of an automatic earthquake detector, based on the *SeisComP* autopicker module. The goal of such a detector is to provide reliable automatic preliminary seismic event detections. So far, this task was performed by our in-house software *JSTAR* ([Polozov & Hofstetter, 2013](#)), which was no longer suitable for the upgraded Israeli Seismic Network, now including 100+ stations ([Kurzon et al., 2020](#)). Therefore, we tested different configuration parameters in order to maximise local earthquake detections, reach the lowest possible magnitude of completeness ($M < 2$) and minimise false detections. Seismic stations were selected based on their noise levels to further optimise the detection procedure. After testing our final configuration in real time, the new procedure was implemented on January 30th, 2024. We present here the adopted configuration and performances from a month-long testing period in December 2023. We find that, compared to the previous detector, the daily rate of false alerts has dropped by 69%, the minimum detected and confirmed magnitude was $M_{1.0}$ and the expected magnitude of completeness is $M_c 2.2$. The average number of detected events for that same period is 17 events per day, of which a daily average of ~8% are natural local earthquakes. Our team of analysts uses the automatic detections as the starting point of manual analysis to provide detailed seismic events information to stakeholders, researchers and the public. The data is publicly available at <https://eq.gsi.gov.il>.

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Introduction

The main missions of the Geological Survey of Israel's (GSI) Seismological Division consist of (i) monitoring the seismic activity in the region and publishing the seismic catalogue, used for risk assessment (e.g., [Wetzler & Kurzon, 2016](#); [Sharon et al., 2020](#); [Yagoda-Biran et al., 2021](#)), (ii) alerting the public and emergency respondents for dangerous earthquakes, by the TRUAA Earthquake Early Warning System (EEWS; e.g., [Nof & Kurzon, 2021](#); [Nof et al., 2021](#)) and (iii) advancing the study of Seismology in Israel (e.g., [Wetzler et al., 2019](#); [Wetzler et al., 2021](#); [Sharon et al., 2022](#); [Ben-Dor et al., 2024](#)). Following the major upgrade of the [Israeli Seismic Network](#) (ISN) as part of the [TRUAA](#) project ([Kurzon et al., 2020](#)), the Division had to face challenges presented by the increase in seismic stations and data, as well as the limitations of the existing software. Therefore, it was decided to gradually shift from the *JSTAR* software ([Polozov & Hofstetter, 2013](#)), developed and maintained in the Division, into the *SeisComP* software package, well established and widely used within the seismological community. In order to make this shift as smooth as possible, and obtain from the new software the maximum benefit, we entered a carefully controlled process of configuration, testing and implementing of a real-time procedure for the detection of local earthquakes (<150 km from Israeli borders). After configuring and setting up an automatic locator (*autolocator*) for significant ($M \geq 2.8$) local earthquakes (see [Appendix A](#)), we used the resulting *SeisComP* modules configuration and went through several iterations of parameters in order to design a more sensitive ($M \approx 2$) local earthquake (LOC) autolocator.

1. Autolocator configuration

a. Station inventory

Similarly to the configuration used for the $M \geq 2.8$ autolocator ([Appendix A](#)), almost all of TRUAA seismometers were included in the LOC autolocator inventory. A few stations were rejected because of their high noise levels (e.g., IS.KFSB, IS.KSRY), or unreliability (boreholes difficult to maintain and check; e.g., IS.MSBI). To these instruments, we added three (out of 17) stations of the Mt. Meron Seismic Array (MMAI), as well as one of the quietest historical ISN stations (IS.PRNI) and two [GEOFON](#) ([GE](#)) stations to increase the autolocator's station aperture towards Cyprus (GE.CSS) and Jordan (GE.GHAJ). Finally, a total of 29 ISN accelerometers were also included in a later update (see [Table 3](#)), in order to increase the sensitivity of the autolocator ([Figure 1](#)).

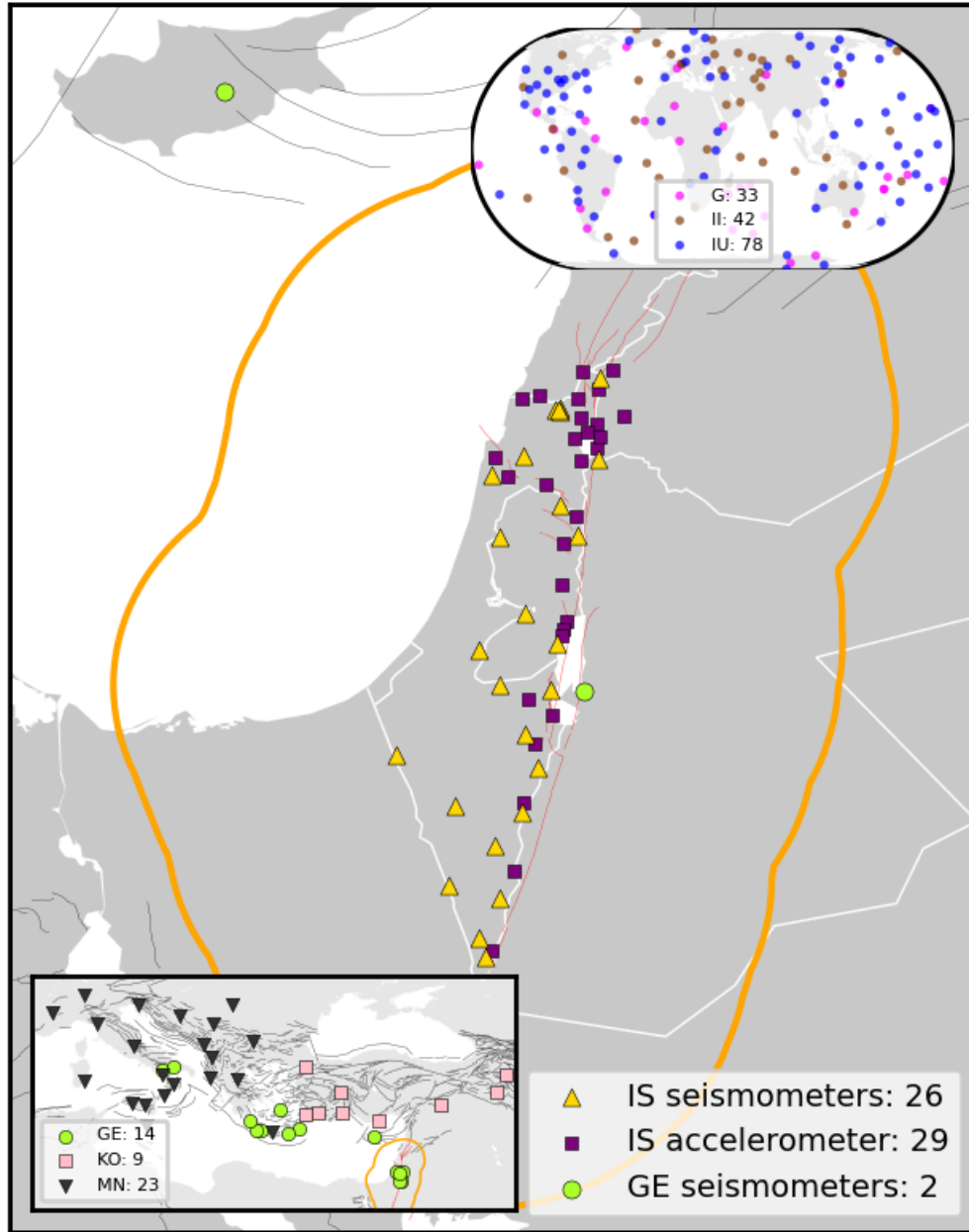


Figure 1: Location of seismic stations used for the autolocators: ISN (IS; yellow triangles) and GEOFON (GE; green circles) seismometers, and ISN accelerometers (purple squares) used for the LOC autolocator. Local (red lines; Sharon et al., 2020) and regional faults (grey lines; Global Earthquake Model) and the limits of the local area of interest (orange line) are also displayed. Inset maps show seismic stations used for the TELE autolocator at regional (bottom left) and global scale (top right): GEOSCOPE (G; magenta dots), Global Seismograph Network IRIS/IDA (II; brown dots), Global Seismograph Network IRIS/USGS (IU; blue dots), Mediterranean Very Broadband Seismographic Network (MN; black triangles), Kandilli Observatory and Earthquake Research Institute (KO; pink squares).

Table 1: List of ISN stations used for the LOC autolocator and corresponding parameters: station code (NET.STA), location, latitude (°N), longitude (°E), altitude (in m) and channel code, describing the instrument type (EN = accelerometer; BH, HH, SH = seismometer). Currently inoperative stations are displayed in grey. Station colouring is similar to that in [Figure 1](#).

Station	Location	Latitude	Longitude	Altitude [m]	Channel
IS.AKAT	Amatzia, IL	31.5491	34.9123	372	22_HH
IS.ALMT	Alumot, IL	32.708	35.5468	64	21_EN
IS.ARD	Arad, IL	31.2497	35.2207	608	21_EN
IS.BLGI	Beit Lehem Haglilit, IL	32.7338	35.1918	187	22_HH
IS.BROR	Beer Ora, IL	29.7109	34.9861	121	21_EN
IS.BTOR	Beit Oren, IL	32.7299	35.0058	387	21_EN
IS.DMNA	Dimona, IL	31.0365	35.1949	466	22_HH
IS.DSHN	Dishon, IL	33.0829	35.5195	457	21_EN
IS.DSI	Dragot, IL	31.5918	35.3933	50	22_HH
IS.EFSH	Ein Fashha, IL	31.7226	35.4537	-83	21_EN
IS.EIL	Eilat Tunnel, IL	29.6723	34.9520	245	22_HH
IS.ENGV	Ein Gev, IL	32.7815	35.6385	172	21_EN
IS.GEM	Giv'at HaEm, IL	33.2106	35.6631	223	22_HH
IS.GLHS	Golan Heights South, IL	32.7136	32.7136	320	22_HH
IS.HDNS	Had Ness, IL	32.928	35.6412	0	21_EN
IS.HMDT	Hemdat, IL	32.2547	35.5273	174	22_HH
IS.HMRA	Hamra, IL	32.1999	35.4357	-23	21_EN
IS.HNTI	Hanita, IL	33.0827	35.1742	301	21_EN
IS.HRFI	Harif, IL	30.0364	35.0370	439.2	22_HH
IS.IDAN	Idan, IL	30.8333	35.2727	-172	22_HH
IS.IZRL	Izrael, IL	32.5629	35.3227	104	21_EN
IS.JER	Jerusalem, IL	31.7724	35.1981	777	22_HH
IS.KNHM	Kfar Nahum, IL	32.8837	35.5792	174	21_EN
IS.KRMI	Karmit, IL	30.1179	34.7256	505	22_HH
IS.KSH0	Keshet, IL	32.9816	35.811	738	21_EN
IS.KZIT	Ktzi'ot, IL	30.9068	34.3978	239.8	22_HH
IS.LVBS	Lehavot Habashan, IL	33.1409	35.6497	118	21_EN
IS.MBRI	Bereh, IL	29.7945	34.9147	852	22_HH
IS.MEHL	Mehola, IL	32.3658	35.516	149	21_EN
IS.MGDL	Migdal, IL	32.8403	35.5072	-83	21_EN
IS.MMB3	Mt. Meron, IL	33.0195	35.3871	811.8	_BH
IS.MMC2	Mt. Meron, IL	33.0268	35.4116	701	_BH
IS.MMC4	Mt. Meron, IL	33.0072	35.4186	749.8	_BH
IS.MMLI	Malkishua, IL	32.4380	35.4220	541	22_HH
IS.MRON	Mt. Meron, IL	33.0152	35.4030	795	22_HH
IS.MSAM	Misgav, IL	33.2469	35.5487	834	21_EN
IS.MSBI	Metzada, IL	31.3126	35.3580	10	22_HH
IS.MSPR	Sapir, IL	30.6145	35.1862	2	21_EN

Station	Location	Latitude	Longitude	Altitude [m]	Channel
IS.NATI	Neve Ativ, IL	33.262	35.7363	1003	21_EN
IS.NVZR	Neve Zohar, IL	31.1535	35.3651	-29	21_EN
IS.OFRI	Ofer, IL	32.6216	34.9862	161	22_HH
IS.ORTZ	Oretz Creek, IL	30.9763	35.2605	1	21_EN
IS.OVNT	Ovnat, IL	31.6796	35.4341	15	21_EN
IS.PRNI	River Paran, IL	30.3522	35.0052	411	_SH
IS.RMNI	Mitzpeh Ramon, IL	30.5970	34.7626	874	22_HH
IS.RMOT	Ramot, IL	32.8515	35.6645	12	21_EN
IS.RSFT	Ramat Hashofet	32.6083	35.0929	272	21_EN
IS.RSPN	Rosh Pina, IL	32.9704	35.5463	376	21_EN
IS.SLTI	Salit, IL	32.2407	35.0410	250	22_HH
IS.TMR	Tmarim Creek, IL	31.6355	35.4220	15	21_EN
IS.YATR	Yatir, IL	31.3400	35.0365	649	22_HH
IS.YFRK	Yafruk, IL	30.1997	35.1308	250	21_EN
IS.YITV	Yitav, IL	31.9469	35.4229	-61	21_EN
IS.ZFRI	Zofar, IL	30.5654	35.1785	-37	22_HH
IS.ZRT	Zar'it, IL	33.1015	35.2901	678	21_EN
GE.CSS	Mathiatis, CY	34.9611	33.3310	396	_SH
GE.GHAJ	Ghor Haditha, JO	31.3034	35.5665	-58	_HH

b. SeisComP modules configuration

Based on *gempa's* own recommended configuration for the monitoring of local earthquakes (see [here](#)), we first designed a procedure to detect local significant earthquakes ([Appendix A](#)). The most important configuration parameters are listed in [Table 2](#). To summarise, real-time vertical-component waveforms are band-pass filtered between 4 and 8 Hz, and then processed by a short-term average over long-term average (STA/LTA) detector with respective time windows of 0.2 and 10 s. A *P* pick is created once the STA/LTA amplitude exceeds a threshold value of 3. The detector is then turned off until the trace amplitude either (i) decreases back to a threshold value of 2 or (ii) is at least twice as low as the *P* pick amplitude. A second detector is next activated on horizontal components in order to detect *S* phases, using in this case a 1–9 Hz band-pass filter. *P* and *S* and picks are kept if their corresponding signal-to-noise ratio (SNR) values exceed 2 and 3, respectively. Finally, an event is created if at least 6 seismic phases were detected.

Table 2: Main configuration parameters used for the $M \geq 2.8$ and LOC autolocator. Trace filters were not modified; see [Appendix A](#) for more details about $M \geq 2.8$ autolocator configuration parameters; RMHP: Running-mean high-pass filter, BW: Butterworth band-pass filter, STA/LTA: short-term / long-term average, SNR: signal-to-noise ratio.

Parameter	Value	
	$M \geq 2.8$	LOC
Trace filter (P)	RMHP(10) >> BW(4, 4, 8) >> STALTA(0.2, 10)	
Trace filter (S)	RMHP(1) >> BW(4, 1, 9)	
Onset STA/LTA threshold (Trigger On)	4.5	3
Restart STA/LTA threshold (Trigger Off)	2	2
Minimum amplitude offset for restart	4	2
Minimum SNR (P)	4	2
Minimum SNR (S)	3	3
Minimum number of phases	7	6

From the initial *SeisComp* module configuration tested and implemented for the $M \geq 2.8$ autolocator ([Appendix A](#)), we applied subsequent updates, each time followed by a testing period for which event detection statistics were collected ([Table 3](#)). The initial configuration used the parameters from the $M \geq 2.8$ autolocator configuration and all ISN seismometers (see [Figure A1](#) and [Table A1](#)). The first update involved reducing the number of seismic phases necessary to the creation of an event, from 10 (default value) to 7. We used these settings for the $M \geq 2.8$ autolocator's final configuration. For the next setup, we consulted with our station survey analyst who periodically reviews station parameters and determines their status ([Kalmanovich, 2017](#)). From the analysis and cross-referencing of multiple proxies (site surveys, signal interruptions, noise levels, etc.), he provides the Division with station reports and classifies them according to three ranks: *Reference*, *Normal* and *Below Normal*. Therefore, we took all accelerometers from the list of *Reference* stations, removed those which are colocated with a seismometer and included them in the station inventory for our LOC autolocator. The update before last consisted in drastically reducing the STA/LTA threshold of the seismic phase detector, from 4.5 to 2.5. From this point, the autolocator started to produce *False* events resulting from a random synchronisation of noise sources at different stations. Because our objective is to detect as many, and mostly as low-magnitude, as possible earthquakes, having to manually eliminate *False* events is to be expected. After a few weeks with that configuration, we raised the STA/LTA threshold to 3, as well as adjusted other parameters to the new amplitude levels in the produced picks. This was the last configuration update; a detailed statistical analysis of the subsequent period is presented in [Section 2](#).

Table 3: Updates implemented in order to adapt the initial $M \geq 2.8$ autolocator configuration (see [Appendix A](#)) to reach a magnitude detection level of $M \approx 2$. The second update was the one actually implemented for the $M \geq 2.8$ autolocator. Performance scores for (i) all, (ii) $M \geq 1.5$, (iii) $M \geq 2$ and (iv) $M \geq 2.5$ events after each configuration change are shown. These scores are calculated as the weighted (by magnitude) sum of True local earthquakes (explosions are reported without magnitudes) divided by the weighted sum of True and Missed local earthquakes; False events are ignored in the calculation because they are non-existent until the last update, and because many have no magnitude estimation.

Time period	Configuration	Performance scores			
		All	$M \geq 1.5$	$M \geq 2$	$M \geq 2.5$
2023-07-05 2023-08-07	Initial configuration for $M \geq 2.8$ autolocator	6.6%	8.8%	19.8%	52.1%
2023-08-07 2023-09-20	Min. number of phases per event decreased from 10 to 7	36.7%	43.8%	71.9%	86.9%
2023-09-20 2023-11-14	Added 29 accelerometers to autolocator inventory	57.2%	64.0%	77.2%	87.1%
2023-11-14 2023-11-30	Decreased onset STA/LTA threshold from 4.5 to 2.5	65.2%	68.5%	81.4%	100%
from 2023-11-30	Increased STA/LTA threshold to 3, min. SNR and amplitude offset decreased to 2 and min. no. of phases decreased to 6	78.8%	82.4%	94.2%	100%

2. Performance

In this section, we present details of a month's worth of automatic event detections following the last configuration update, between November 30th and December 31st of 2023.

a. Automatic detections

A total of 1,925 events were detected by the LOC autolocator ([Figure 2](#)). After visually reviewing all of these events, our team of analysts determined that 588 (30%) were *False* detections (*i.e.*, events with non-seismic signals). As a comparison, the in-house RTLOC/PYLOC detectors ([Polozov & Hofstetter, 2013](#)) currently in use at the Division triggered 1,860 *False* detections over the same period. This represents ~60 *False* events per day, whereas the LOC autolocator only produces less than ~20 events per day, thus reducing the analyst team's work by a factor of 3, since *False* detections still need to be identified and discarded. An interesting observation is the drastically reduced number of *False* events on weekend days, indicating that the noise bursts triggering these events are mostly anthropogenic. Fine tuning based on stations' noise levels (*e.g.*, turning off particularly noisy stations during the week) might help further reduce the number of *False* detections.

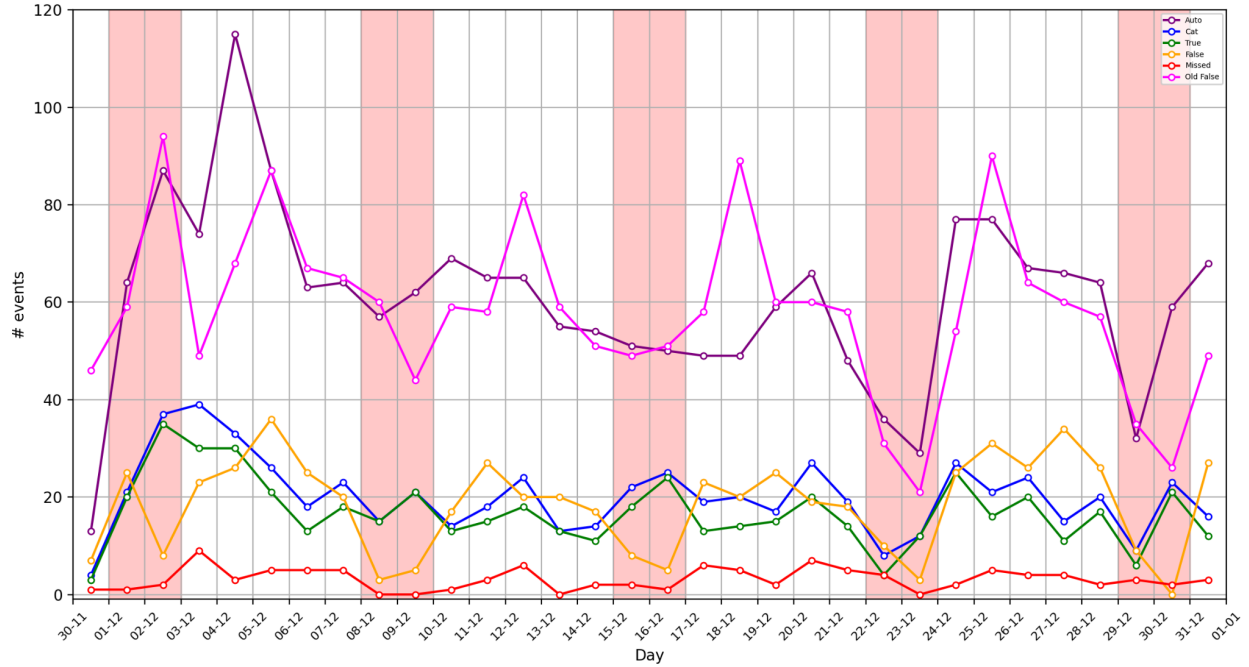


Figure 2: Timeline of event detections over the course of the Nov 30th–Dec 31st trial period: all automatic events (purple), all catalogue events (blue), all True (green), False (orange) and Missed (red) events, as well as False events triggered by the old PYLOC/RTLOC detectors (magenta); weekend days in Israel are indicated (red-shaded areas) to highlight the reduced number of False events on weekends.

The distribution of *False* detections show they occur mostly within Central Israel (Figure 3). Due to the quasi-rectilinear distribution of ISN stations along the Dead Sea Transform fault (DST), *False* detections are spreading East-West, perpendicularly to the DST's orientation. Therefore, and since larger-magnitude *False* detections are more often triggered away from the ISN, large *False* events are limited to the edges of and beyond the “local” area of interest. Moreover, we note that many (43.4%) *False* events are without magnitude, indicating a potential way to flag such events, in order to further reduce the analysts' workload.

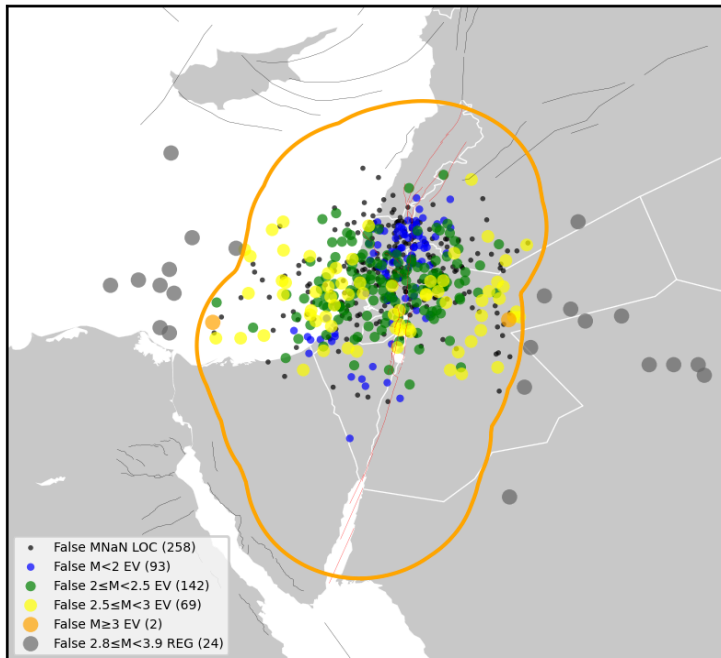


Figure 3: Map of False detections triggered by the LOC autolocator: events with missing magnitude calculation (black dots), local events (EV) colour-coded for several ranges of magnitude (coloured circles) and regional (REG) events (grey circles). Local (red lines) and regional faults (grey lines) and the limits of the local area of interest (orange line) are also displayed.

b. Matching with catalogue events

We extracted all events from the GSI catalogue for the same trial period. This represents a total of 637 seismic events, including local and regional earthquakes as well as man-made explosions. Out of these, 598 are local events, with a minimum magnitude of 1.0, and 39 are regional events, with a minimum magnitude of 2.6. From here on, we define three categories of detections, in order to compare automatic and catalogue events: (i) *True* detection is defined when an event in the catalogue was detected by the autolocator, (ii) *Missed* detection is defined when an event in the catalogue was not detected by the autolocator, and (iii) *New* detection is defined when a real event does not have a catalogue match (*i.e.*, not detected by the currently in-use RTLOC/PYLOC detectors).

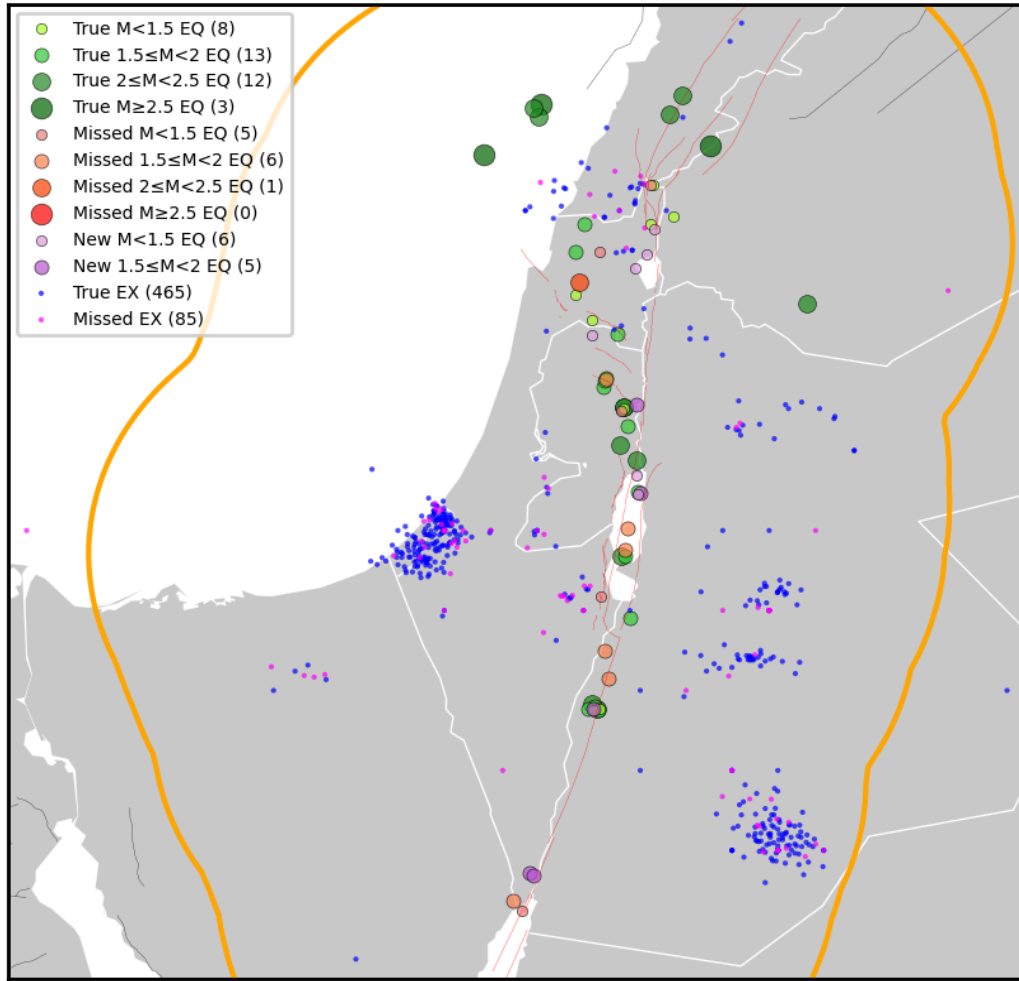


Figure 4: Map showing both earthquakes and explosions. For local earthquakes (EQ): True (green circles), Missed (red circles) and New (purple circles) detections, for several magnitude ranges (see legend). For local explosions (EX): True (blue dots) and Missed (magenta dots) detections. The locations of True and Missed detections are from the GSI catalogue, whereas the locations of New events are from the LOC autolocator. Local (red lines) and regional faults (grey lines), as well as the limits of the local area of interest (orange line) are also displayed.

Table 4: Number of True and Missed local event detections after comparison between the LOC autolocator and the GSI catalogue, for several magnitude ranges, and for explosions (EX).

Magnitude range	True	Missed
$M < 1.5$	8	5
$1.5 \leq M < 2.0$	13	6
$2.0 \leq M < 2.5$	12	1
$M \geq 2.5$	3	0
EX with no explicit M	465	85

By comparing automatic and catalogue detections (see Table 4 and Figure 3), we counted a total of 501 (83.8%) *True* local events and 36 (92.3%) *True* regional events, as well as 97 (16.2%) *Missed* local events and 3 (7.7%) *Missed* regional events. Overall, events detected in Israel are mainly anthropogenic: primarily quarry blasts from Israel, Jordan and Egypt, but also illegal fishing blasts from Lebanon, or even controlled explosions of old ammunition. Since October 7th, numerous detections are the results of the Iron Swords War, in either Gaza, Southern Lebanon or the Golan Heights. Therefore, most catalogue events are *not* earthquakes: 73% of *True* events and 87.6% of *Missed* detections were explosions.

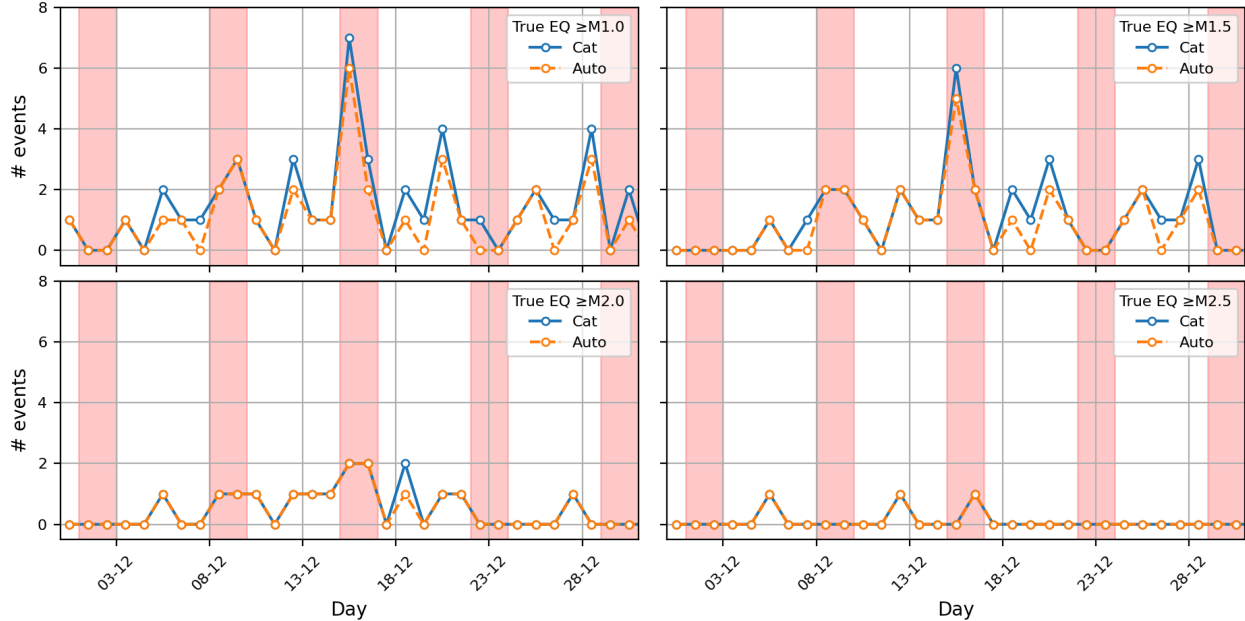


Figure 5: Timelines of automatic (blue) and catalogue (orange) True event detections for all magnitudes above (i) 1.0, (ii) 1.5, (iii) 2.0 and (iv) 2.5.

After removing all explosions from the analysis, we examine only earthquakes, with 36 *True* and 12 *Missed* local events. Most *True* detections correspond to events that occurred along the DSF and Carmel-Tirtza Fault (CTF) systems, as well as inland and offshore Lebanon. Around the CTF

and Kinneret, we seem to be able to detect lower magnitudes, most likely due to the higher station density in the area. *Missed* earthquakes all but one have magnitudes lower than 2 and are generally more frequent in areas where station density is lower (e.g., in Southern Israel). By comparing the timelines of *True* detections for automatic and catalogue events (Figure 4) organised in several magnitude ranges, we can see them diverging for $M \geq 2$ events, but completely overlap for $M \geq 2.5$ events. This indicates that, for this month-long trial period, we reached an estimated magnitude of completeness of $M_c \sim 2.2$, since the largest *Missed* event was an $M_{2.1}$ event in the CTF area, corresponding to the difference between $M \geq 2$ timelines.

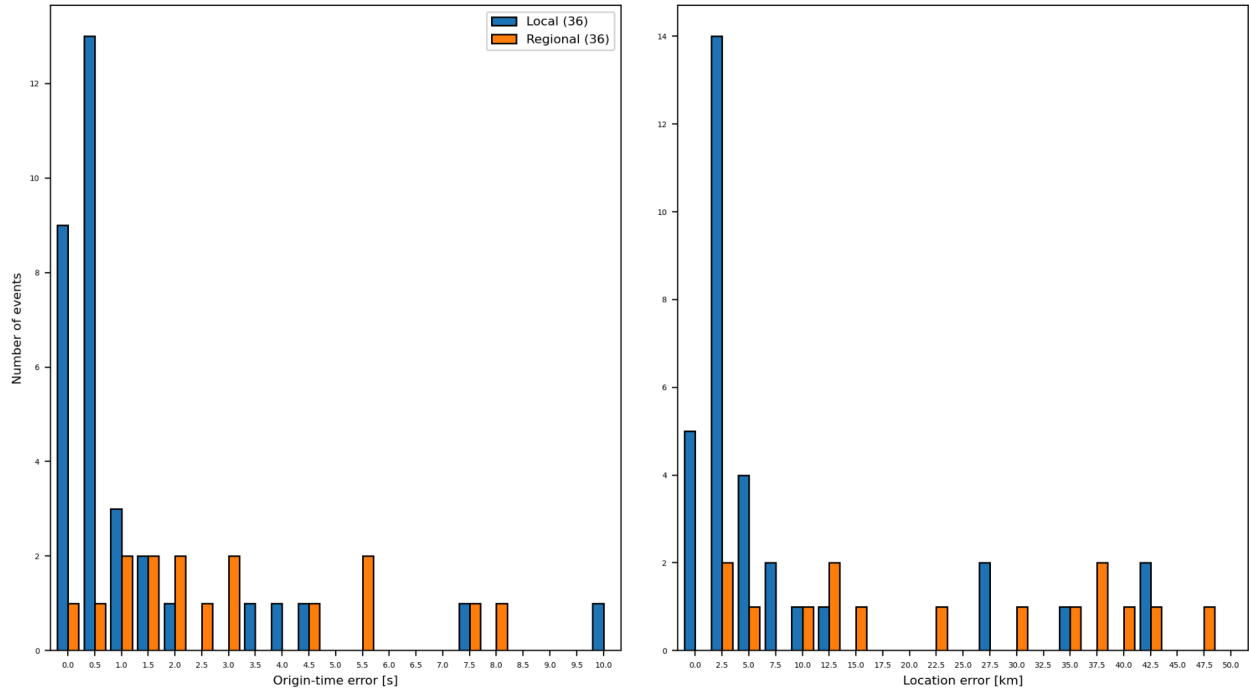


Figure 6: Differences in origin time (left) and epicentral location (right) between automatic and GSI catalogue events corresponding to True detections of local (blue) and regional (orange) events.

The comparison between origin parameters for automatic and catalogue events (Figure 6) demonstrate an acceptable level of uncertainty. Origin-time differences are below 1 s, and epicentral location differences below 5 km, which is to be expected for automatic local-event locations resulting primarily from *P*-wave picks.

We visually checked the 797 real automatic events not present in the GSI catalogue and estimated ~50% of them were the result of the Iron Swords War. About 20% are quarry blasts, mainly from Jordan, but also from all over Israel. Moreover, many events were not locatable without further processing (e.g., many seismic events are only visible at Mt. Meron Array, which does not provide enough aperture for an accurate location). Our analysts reviewed some of the events left and found at least 11 *New* local earthquakes (Figure 3) that have since then been added to the GSI catalogue. All *New* events have magnitudes below 2, like all *Missed* events except for the $M_{2.2}$ Carmel event, and are not found in any specific area, but all over Israel, like *Missed* events. This overlap of events missed by both detection procedures show that they now

have similar detection capabilities, with a magnitude threshold around 2. In order to further lower this threshold, we will need to configure dedicated *SeisComP* modules and run statistical analyses on stations in order to fine tune the autolocator at the station level (see [Section 3](#)).

c. Autolocator dedicated to distant events

In parallel to the LOC autolocator, we also configured and set up an automatic locator for teleseismic and regional events (TELE). For this autolocator, we used the default *SeisComP* configuration designed for the monitoring of global seismicity, in which waveforms are band-pass filtered between 0.7 and 2 Hz and the picker is triggered once a trace's STA/LTA ratio reaches values above 3.

Currently, the station inventory for the TELE autolocator is set with four global seismic networks ([GE](#), [G](#), [II](#) & [IU](#)), and two regional networks ([KO](#) & [MN](#)). We are expecting to add to this the Cyprus Broadband Seismological Network ([CQ](#)), which will be made available to us once our collaboration with the Cyprus Geological Survey is finalised. In order to further improve our regional detection capabilities, we would ideally add other regional networks (*e.g.*, Mediterranean Sea and Central Asia), but this will need further investigation to overcome data accessibility issues.

The TELE autolocator enables us to observe global seismicity in real time. It also helps detect some *local* events that occur at distances too large for the LOC autolocator to produce an accurate detection. For such events whose signals include lower frequencies than those of local events, the TELE autolocator's filter may perform better. This is particularly the case at the edges of the ISN, like in Jordan, as well as for more distant regional earthquakes (*e.g.*, Central Mediterranean Sea, Northern and Eastern Turkey, etc.). The TELE autolocator does not produce any *False* events, but may produce occasional duplicates, particularly for events in such a distance range that they may generate frequencies matching both autolocator filters.

We checked all detections of teleseismic and regional earthquakes from both the LOC and TELE autolocators against the GSI and Euro-Mediterranean Seismological Centre ([EMSC](#)) catalogues. After matching with the GSI catalogue, we noted 36 *True* and 3 *Missed* regional events ([Figure 7](#)). Most *True* events are located in Cyprus, Syria, the Eastern Mediterranean Sea and Suez Gulf. The few *Missed* earthquakes occurred relatively close by, but were also low magnitudes. The 20 *New* events (*i.e.*, not in the GSI catalogue) detected by the TELE autolocator were matched with EMSC events. Most of them occurred at the Turkey/Syria and Turkey/Greece borders, and some are intermediate-distance, low-magnitude earthquakes. The contribution of the TELE autolocator mostly concerns more distant and larger-magnitude earthquakes in Northern, Central and Eastern Turkey.

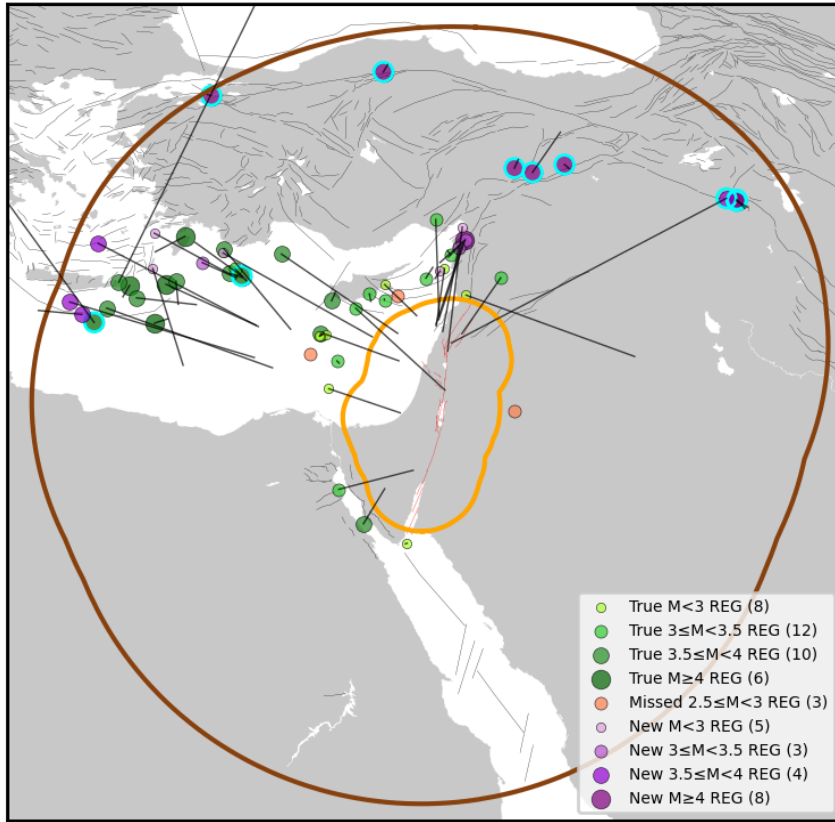


Figure 7: Map showing True (green circles), Missed (red circles) and New (purple circles) detections of regional earthquakes (REG) for several magnitude ranges (see legend). Locations of True and Missed events are from the GSI catalogue, whereas locations of New events are from the EMSC catalogue. Black lines point to the initial automatic locations and cyan indicates a detection that originated from the TELE autolocator. Local (red lines) and regional (grey lines) faults and the boundary of the local (orange line) and “regional” (brown line) areas of interest are also displayed.

3. Future work

We are continuously trying to improve our automatic and manual monitoring and processing capabilities. These efforts include (i) further exploring and testing of the existing autolocator (as presented in this report), (ii) implementing additional advanced modules from the *SeisComp* software package and (iii) generating station-tailored configurations for detection and association schemes.

a. Use of playbacks to explore a wider range of detection and association parameters

The current configuration of the LOC autolocator was implemented on a real-time machine, “listening” to the network as data accumulates. Although this method is a one-to-one imitation of the real-time process, it is dependent on the rate and variability of seismicity within the examined time period. This constrains the time it takes to configure the autolocator best suited to the network topology. Therefore, a faster and more efficient solution would be to run parallel playbacks (using previously recorded waveform files to re-run the analysis of an old event), where different configurations can be tested over the same database of waveforms, and in which a month of data can be processed in only a few days of actual run time. This would help further improve configuration parameters and lower the magnitude of completeness – leading to a more sensitive network, with better performance of the automatic procedures, and with more robust scientific products.

b. Use of other dedicated SeisComP modules

The *SeisComP* package offers practical and flexible solutions to improve the monitoring and processing of earthquake data. Modules dedicated to the detection of specific types of seismicity are also available, and need to be tested and implemented at the Seismological Division.

The *SeisComP* module [*scanloc*](#) is designed to monitor local and micro seismicity within networks such as the ISN. The *scanloc* module makes use of a cluster search algorithm to associate phase detections to one or many potential earthquake sources. While the cluster search itself is based on *P* phases only, *S* phases are also associated in a second step and used for locating earthquakes. In order to provide high-quality picks from *S* phases, a new *S* picker is distributed along with *scanloc*. The *S* picker allows identifying *S* phases on horizontal components, or on vertical components if horizontals are unavailable.

The *SeisComP* module [*ccloc*](#) detects large but also very weak or distant earthquakes by matching waveform templates from known master events to real-time or archived data. The matching is done by cross-correlation of processed data. The data processing includes any filter available in *SeisComP*. Such filtered waveforms and even envelopes or STA/LTA traces can be used as characteristic functions. The *ccloc* module does not require discrete picks. Therefore, the sensitivity of a monitoring network can be increased and the magnitude of completeness can be lowered. As *ccloc* can remember the event type of master events, new detections may be classified and events of different types, *e.g.*, earthquakes and explosions can be discriminated against. The *ccloc* module has been optimised for efficient processing of large datasets and simultaneous application of many template events.

The *SeisComP* module [*sceval*](#) automatically discriminates real earthquakes from fake solutions. Reliable automatic monitoring of earthquakes at low magnitudes is challenging due to the low number and the possibly low quality of available phase detections. Therefore, automatic systems are often tuned to only accept robust solutions with many observations preventing fake events. Such systems potentially miss weak events resulting in incomplete earthquake catalogues. With this module, seismic monitoring systems can be tuned to even accept very weak events detected under unfavourable conditions. This way, earthquake catalogues can reach high completeness while being clean from fakes and operators can focus on analysing the most relevant events. Tuning of such event discrimination may be time-consuming and difficult. Therefore, *sceval* comes with a self-tuning tool providing the optimum configuration parameters based on manual observations.

c. Station monitoring for automatic detector reconfiguration

In order to make the autolocators more automatically adapting, without entering into machine learning territory, there are at least two ways real-time station monitoring can be used to minimise the integration of detected noise bursts with actual seismic phases, and more generally to further reduce the number of *False* detections.

First, station data quality and availability should be monitored in real time in order to quantify the amount of background noise, gaps, spikes and other punctual disruptions (a long station outage will not produce many non-seismic picks). Based on immediate, but also longer-period statistics (*e.g.*, in order to increase detection thresholds or even turn off a station near a source of high anthropogenic noise during the day or week), a decision module could have an ensemble of conditions (*e.g.*, number of gaps per hour, noise level, etc.) helping to adapt a given station's detection configuration.

Secondly, station statistics in terms of their participation to *True* and *False* detections, or absence from *Missed* detections, could help classify and determine the best station selection without requiring real-time processing, and should at least match the analyst team's workflow (*e.g.*, by producing such statistics during the night and adapting a given station's detection configuration before the next day).

Summary

The first stage of configuring and implementing a stable and reliable autolocator for local seismicity has been completed. The new autolocator provides automatic detections with a magnitude of completeness of $M_c 2.2$ for local events, defined as events located up to 150 km from Israeli borders. However, we believe a lower magnitude of completeness can be achieved, mostly thanks to the high station density of the ISN. Nevertheless, the value of $M_c 2.2$ is accepted at this stage for the production of the GSI seismic catalogue. In order to further improve the autolocator, we will refine configuration parameters through the use of waveform playbacks, allowing the testing of a maximum number of parameter values within a minimum amount of time.

Appendix A: SeisComp modules configuration for the detection of significant ($M \geq 2.8$) local earthquakes

This appendix documents the ideal software configuration reached in order to provide correct preliminary seismic event parameters for local $M \geq 2.8$ earthquakes.

a. Station inventory

The upgraded ISN ([Kurzon et al., 2020](#)) consists of 114 strong-motion accelerometers, some of which are combined with broadband seismometers and/or Global Navigation Satellite Systems (GNSS) receivers ([Figure A1](#)).

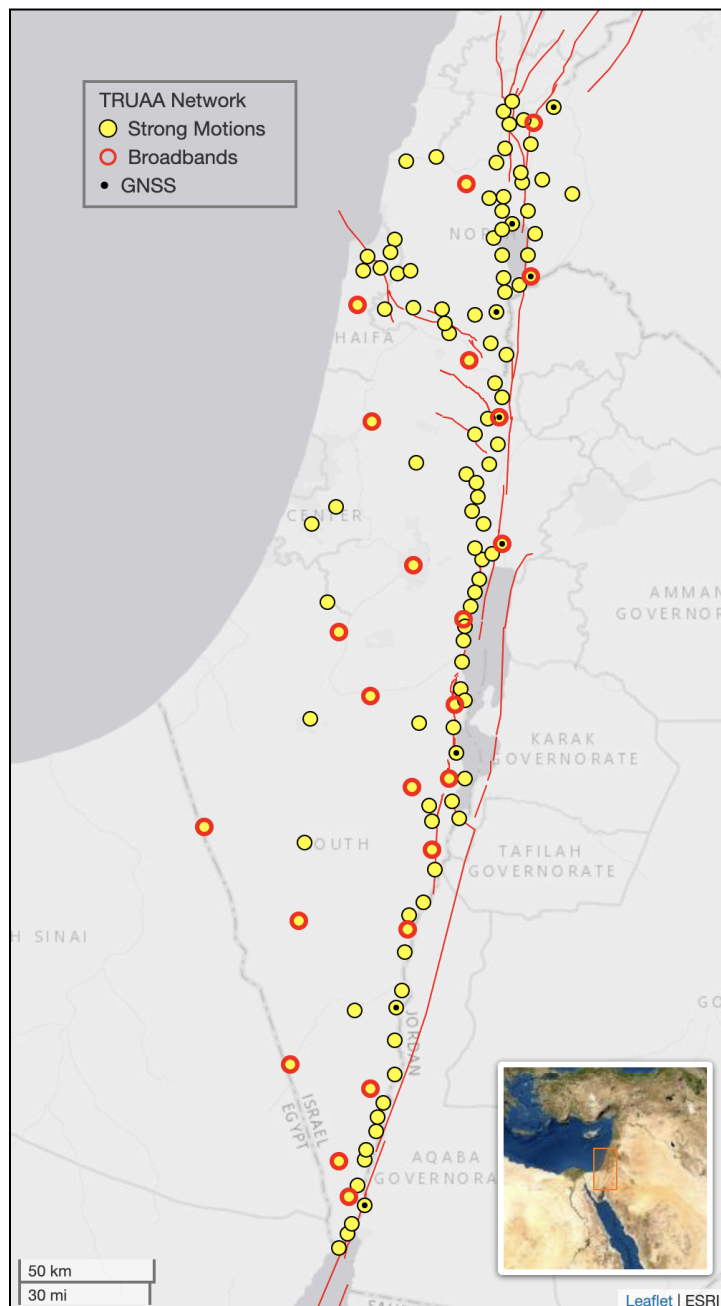


Figure A1: Location map of ISN stations: strong-motion sensors (yellow circles), sometimes co-located with broadband seismometers (red circles) and/or GNSS receivers (black dots). Active faults are also represented (red lines). Modified after [Nof et al. \(2021\)](#).

Because our aim here is mainly to monitor significant ($M \geq 2.8$) local earthquakes, we limit the instruments used to ISN seismometers (red circles in [Figure A1](#)), for which the coverage is sparser and will therefore not detect small ($M < 2.0$) events and focus on potentially dangerous earthquakes. We also removed borehole stations, which are very difficult to maintain, and for which the metadata is therefore more likely to be erroneous. This represents a total of 29 seismic stations across the country, to which we added two stations of the [German GeoForschungsZentrum's](#) (GFZ) *GEOFON* global seismic network (GE; [GEOFON Data Centre, 1993](#)) in Cyprus (GE.CSS) and West Bank (GE.GHAJ) in order to improve the automatic detector's visibility to potentially dangerous earthquakes in these areas (see [Table A1](#)).

Table A1: Station parameters used in the $M \geq 2.8$ autolocator configuration: network and station codes, location, latitude ($^{\circ}$ N), longitude ($^{\circ}$ E), altitude (in m) and channel code; IL: Israel, CY: Cyprus, JO: Jordan.

Station	Location	Latitude	Longitude	Altitude [m]	Channel
IS.AKAT	Amatzia, IL	31.5491	34.9123	372	22_HH
IS.BLGI	Beit Lehem Haglilit, IL	32.7338	35.1918	187	22_HH
IS.DMNA	Dimona, IL	31.0365	35.1949	466	22_HH
IS.DSI	Dragot, IL	31.5918	35.3933	50	22_HH
IS.EIL	Eilat Tunnel, IL	29.6723	34.9520	245	22_HH
IS.GEM	Giv'at HaEm, IL	33.2106	35.6631	223	22_HH
IS.GLHS	Golan Heights South, IL	32.7136	32.7136	320	22_HH
IS.HMDT	Hemdat, IL	32.2547	35.543	174	22_HH
IS.HRFI	Harif, IL	30.0364	35.0370	439.2	22_HH
IS.IDAN	Idan, IL	30.8333	35.2727	-172	22_HH
IS.JER	Jerusalem, IL	31.7724	35.1981	777	22_HH
IS.KRMI	Karmit, IL	30.1179	34.7256	505	22_HH
IS.KZIT	Ktzi'ot, IL	30.9068	34.3978	239.8	22_HH
IS.MBRI	Bereh, IL	29.7945	34.9147	852	22_HH
IS.MMB3	Mt. Meron, IL	33.0195	35.3871	811.8	_BH
IS.MMC2	Mt. Meron, IL	33.0268	35.4116	701	_BH
IS.MMC4	Mt. Meron, IL	33.0072	35.4186	749.8	_BH
IS.MMLI	Malkishua, IL	32.4380	35.4220	541	22_HH
IS.MRON	Mt. Meron, IL	33.0152	35.4030	795	22_HH
IS.MSBI	Metzada, IL	31.3126	35.3580	10	22_HH
IS.OFRI	Ofer, IL	32.6216	34.9862	161	22_HH
IS.PRNI	River Paran, IL	30.3522	35.0052	411	_SH
IS.RMNI	Mitzpeh Ramon, IL	30.5970	34.7626	874	22_HH
IS.SLTI	Salit, IL	32.2407	35.0410	250	22_HH
IS.YATR	Yatir, IL	31.3400	35.0365	649	22_HH
IS.ZFRI	Zofar, IL	30.5654	35.1785	-37	22_HH

Station	Location	Latitude	Longitude	Altitude [m]	Channel
GE.CSS	Mathiatis, CY	34.9611	33.3310	396	_SH
GE.GHAJ	Ghor Haditha, JO	31.3034	35.5665	-58	_HH

b. Automatic seismic phase picker

We use the [scautopick](#) *SeisComP* module in order to automatically pick seismic arrivals on waveforms, in real time. Waveforms are band-pass filtered between 4 and 8 Hz, the main frequency range of seismic waves emitted by local earthquakes. We decided not to apply a taper, since it tends to keep the detector “blind” for a while after the initial detection has been made. A short-term/long-term average (STA/LTA) ratio is applied to waveforms for making detections, with respective time windows of 0.2 and 10 s. These optimal values of filter and detector parameters were found after running different series of event detection tests using offline and online playbacks. Once the STA/LTA ratio has reached a threshold value of 4.5, a pick is set. The picker is then reactivated once the STA/LTA ratio falls to the value of 2. We enable the Akaike Information Criterion (AIC) re-picker ([Maeda, 1985](#); [Zhang, 2003](#)) for both primary (P) and secondary (S) seismic phases. All non-default parameters for *scautopick* are listed in [Table A2](#).

Table A2: All non-default values used for *scautopick* parameters. These parameters can be defined using the *scconfig* application, in the Modules > *scautopick* section. Alternatively, in the *SeisComP* file system, they can be directly written in the `~/seiscomp/etc/scautopick.cfg` file. See the *SeisComP* documentation for the [scautopick](#) module for more details on these and other parameters; RMHP: running-mean high-pass filter, BW: Butterworth band-pass filter, STALTA: short-term/long-term average filter.

Parameter	Value
initTime [s]	20
gapInterpolation	TRUE
filter	RMHP(10) >> BW(4, 4, 8) >> STALTA(0.2, 10)
timeCorr [s]	0
picker	AIC
spicker	S-AIC
killPendingSPickers	FALSE
amplitudes	MLv, mb, mB, Mwp, M
thresholds.triggerOn	4.5
thresholds.triggerOff	2
thresholds.deadTime [s]	2
thresholds.minAmplOffset	4

In addition to the *scautopick* configuration mentioned above, we also define profiles for each type of instrument (short period [SH], broadband [BH] and high broadband [HH]) and their location. We define corresponding station bindings for *scautopick* using *scconfig*. Coincidentally, this is the only location, as far as we are aware, where it is possible to configure (i) the S-phase picker and (ii) minimum signal-to-noise ratio (SNR) requirements. At the moment, all instrument

profiles are identical, with the exception of enabling sensitivity correction for SH instruments (at station IS.PRNI). For the identification of *S* arrivals, we do not use an STA/LTA detector, and simply apply a band-pass filter around 1 and 9 Hz. *P* and *S* picks are kept if their SNR value exceeds 4 and 3, respectively. All non-default values of *scautopick* station binding parameters are listed in [Table A3](#). We named our station profiles for each instrument type according to the naming convention adopted in [Table A1](#) (*Channel*). Note that in the case of SH instruments, we apply sensitivity correction (`sensitivityCorrection = TRUE` in *scautopick* station bindings).

Table A3: All non-default values used for *scautopick* station binding parameters. Station binding profiles can be created using the *scconfig* application, in the Bindings > *scautopick* > Global section of instrument profiles. Alternatively, in the SeisComP file system, corresponding instrument profiles can be directly created in the `~/seiscomp/etc/key/scautopick/` directory. See the SeisComP documentation for the [configuration of station bindings](#) for more details on how to create such profiles.

Parameter	Value
picker.AIC.filter	RMHP(10) >> BW(4, 4, 8) >> STALTA(0.2, 10)
picker.AIC.minSNR	4
spicker.AIC.noiseBegin [s]	-20
spicker.AIC.signalBegin [s]	2
spicker.AIC.filter	RMHP(1) >> BW(4, 1, 9)
spicker.AIC.step [s]	2
spicker.AIC.minSNR	3

c. Magnitude estimation

Table A4: All non-default values used for *scamp* parameters. These parameters can be defined using the *scconfig* application, in the Modules > *scamp* section. Alternatively, in the SeisComP file system, they can be directly written in the `~/seiscomp/etc/scamp.cfg` file. See the SeisComP documentation for the [scamp](#) module for more details on these and other parameters.

Parameter	Value
amplitudes	MLv, mb, mB, Mwp
amptool.minimumPickWeight	0.3
amptool.initialAcquisitionTimeout [s]	20

In order to estimate event magnitudes, waveform amplitudes are measured for each station, by both *scautopick* and the dedicated [scamp](#) module. The module is configured to compute amplitudes for magnitudes adapted to both local and teleseismic distances. All non-default values of *scautopick* station binding parameters are listed in [Table A4](#).

Station amplitudes (from either *scautopick* or *scamp*) are then used by the [scmag](#) module to compute station and network magnitudes. On top of this, we also enabled and configured a summary magnitude, defined as the weighted sum of all available network magnitudes. All non-default values of *scautopick* station binding parameters are listed in [Table A5](#).

Table A5: All non-default values used for *scmag* parameters. These parameters can be defined using the *scconfig* application, in the Modules > *scmag* section. Alternatively, in the SeisComP file system, they can be directly written in the `~/seiscomp/etc/scmag.cfg` file. See the SeisComP documentation for the [scmag](#) module for more details on these and other parameters.

Parameter	Value
magnitudes	MLv, mb, mB, Mwp
magnitudes.average	mean
summaryMagnitude.enabled	TRUE
summaryMagnitude.type	M
summaryMagnitude.coefficients.a	0, Mw(mB):0.4, Mw(Mwp):0.4
summaryMagnitude.coefficients.b	1, MLv:2, Mw(mB):-1, Mw(Mwp):-1

d. Event location

Seismic events are automatically located in near-real time by the *SeisComP* module [scautoloc](#). It normally runs continuously, reading picks and amplitudes, processing them in real time and trying to identify combinations of picks that correspond to a common seismic event. If the produced location meets certain consistency criteria, a new event origin is created. All non-default values of *scautoloc* parameters are listed in [Table A6](#). The procedure of *scautoloc* to identify and locate seismic events basically consists of the following steps:

i) Pick filtering

The *scautoloc* module receives and filters phase picks to generate origins. These phase picks are used by default if (all other picks are ignored):

- the seismic phase hint is *P*;
- the evaluation mode is “automatic”;
- the evaluation status is not “rejected”;
- the pick “author” is empty or listed in the module configuration;
- and the picks are accompanied by amplitudes.

ii) Pick association

An incoming pick is first attempted to be associated with a known origin. If the association succeeds, the nucleation process is bypassed.

iii) Origin nucleation

If direct association fails, *scautoloc* tries to make a new origin out of the incoming pick and other unassociated, previously received picks. The algorithm performs a grid search over space and time. The spatial grid ([Figure A2](#)) is a discrete set of evenly-spaced points that sample the volume of interest, according to the required resolution.

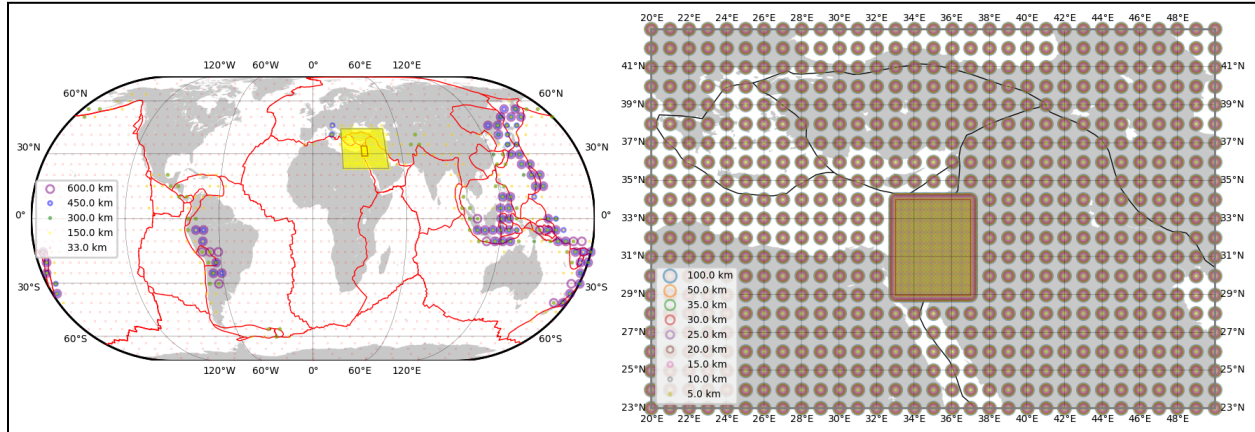
Table A6: All non-default values used for *scautoloc* parameters. These parameters can be defined using the *scconfig* application, in the Modules > *scautoloc* section. Alternatively, in the *SeisComP* file system, they can be directly written in the `~/seiscomp/etc/scautoloc.cfg` file. See the *SeisComP* documentation for the [scautoloc](#) module for more details on these and other parameters.

Parameter	Value
locator.profile	giimod
locator.defaultDepth [km]	5.0
locator.minimumDepth [km]	0.0
autoloc.maxRMS [s]	3.0
autoloc.maxResidual [s]	3.0
autoloc.amplTypeAbs	snr
autoloc.grid	@DATADIR@/scautoloc/grid_regional.conf
autoloc.stationConfig	@DATADIR@/scautoloc/station_regional.conf
autoloc.stationLocations	@DATADIR@/scautoloc/station-locations_regional.conf

In the grid search, each one of the grid points is taken as a hypothetical hypocentre for all incoming picks. Each incoming pick is back projected in time for each of the grid points, on the assumption that it is a first-arrival *P* onset. If the pick indeed corresponds to the *P* arrival of a seismic event, and if this event was recorded at a sufficient number of stations, the back projected new pick will cluster with previous picks from the same event. The cluster will have the highest density around the origin time at the grid point closest to the hypocentre. In principle, the grid could be so dense that the location obtained from the grid search can be used directly. However, as RAM memory as well as CPU speed is limited, this is not possible. Therefore, if a cluster is identified as a potential origin, it does not necessarily mean that all contributing picks actually correspond to *P* arrivals. It may as well be a coincidental match caused by the coarseness of the grid or possible contamination by picked noise. Therefore, the location program *LocSAT* ([Bratt & Nagy, 1991](#)) is run in order to try a location and test if the set of picks indeed forms a consistent hypocentre. If the pick residual root-mean-square (RMS) is too large, a bootstrap procedure is applied, in an attempt to reduce the RMS, by iteratively excluding each one of the contributing picks. If the new origin meets all requirements, it is accepted as a new seismic event location.

In order to apply *scautoloc* for the ISN, we adapted the default search grid provided with the *SeisComP* package. We defined a *local* area between latitudes 27°N and 36°N and between longitudes 32°E and 38°E, as well as a *regional* area between latitudes 11°E and 51°E and between longitudes 15°E and 55°E. Outside of these areas, the *global* grid has a 5° lateral spacing and depths are sampled at 33, 150, 300, 450 and 600 km. The regional and local grids have lateral spacings of 1° and 0.2°, respectively, and depths are sampled every 5 km in the crust, and at 50 and 100 km in the upper mantle (see [Figure A2](#)).

Figure A2: Grid used to search and locate seismic events in SeisComP's *scautoloc* module. Circles represent grid nodes and are coloured according to depth (see legend); **red lines** represent the boundaries of tectonic plates ([Bird, 2003](#)). The default grid initially provided with the software package is shown on the left with the exception of the **yellow rectangle**; within this area we define the regional and local grids shown on the right. The global grid has a 5° lateral spacing, and a vertical resolution that depends on the tectonic environment (e.g., deepest in subduction zones). The regional and local grids have lateral spacing of 1° and 0.2° , respectively, and depths are sampled every 5 km in the crust and at 50 and 100 km in the upper mantle (see legend).



iv) Origin refinement

An origin produced or updated through association and/or nucleation may still be contaminated by phases wrongly interpreted as *P* arrivals. The *scautoloc* module tries to improve these origins based on, e.g., pick SNR or amplitude. In this processing step, it is also attempted to associate phases which slipped through during the first association attempt, e.g., because the initial location was incorrect. If the origin contains a sufficient number of arrivals to assume a reasonable location result, *scautoloc* additionally tries to associate picks as secondary phases such as *pP*. Such secondary phases are only “weakly associated”, i.e., these phases are not used for the location. For the analyst, however, it is useful to have possible *pP* phases predefined.

v) Origin filtering

This process involves final consistency checks of new/updated origins. During this procedure, the origins are not modified any more.

In the course of nucleation and association, as well as in the origin refinement and filtering, certain criteria are applied to compare the quality of concurring origins. These criteria are combined in an internal origin score, which is based on properties of the picks themselves in the context of the respective origin. The configurable criteria that origins must meet in order to be reported are:

- minimum number of phases per origins;
- station residual;
- origin RMS;
- maximum depth;
- azimuthal gap.

In addition, pick amplitudes provide valuable means of comparing origin qualities. Obviously, a pick with a high SNR will less likely be a transient burst of noise than a pick merely exceeding the SNR threshold. A high-SNR pick thus increases the origin score. Similarly, a pick associated with a large absolute amplitude is more likely to correspond to a real seismic onset, especially in case of simultaneous, large-amplitude observations at neighbouring stations.

e. Event association

SeisComp modules create several origins (results of localisation processes) for one seismic event since, as time goes by, more seismic phases are available. The [scevent](#) module receives these origins and associates them to events. It is also possible to import and associate origins from other agencies. The main tasks of *scevent* are:

- associate origins to events;
- set the ID of events;
- set the preferred origin from all available origins;
- set the preferred magnitude from all available magnitudes;
- set the preferred focal mechanism from all available focal mechanisms;
- set the event type of automatic origins based on the plugin [evrc](#) and the hypocentre location of the preferred origin.

We used the default configuration for *scevent* parameters. These parameters can be defined using the *scconfig* application, in the Modules > *scevent* section. Alternatively, in the *SeisComp* file system, they can be directly written in the `~/seiscomp/etc/scevent.cfg` file.

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גילוי אוטומטי של רעידות אדמה מקומיות בישראל

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תקציר

בסוף 2022, אגף הסיסמולוגיה של המכון הגיאולוגי לישראל שדרג את כל מערכות עיבוד הנתונים הסיסמיים על-בסיס תוכנת "סייסקומפ" של חברת "גמפה" (GFZ & gempa, 2008). בדו"ח, אנו מציגים את התכנון והיישום של גלאי רעידות אדמה אוטומטי, המבוסס על מודול ה-*scautopick* של "סייסקומפ". המטרה של גלאי כזה היא לספק זיהוי ראשוני ואמין של אירועים סייסמיים. עד כה, משימה זו בוצעה על ידי התוכנה הביתית של אגף הסיסמולוגיה, *JSTAR* (Polozov & Hofstetter, 2013), אשר הפסיקה להתאים לרשת הסיסמולוגית המשדורגת של ישראל (ה-*ISN*), הכוללת כיום יותר מ-100 תחנות סיסמיות (Kurzon et al., 2020). לשם כך, בדקנו פרמטרים שונים על מנת: א. למקסם זיהוי רעידות אדמה מקומיות, ב. להגיע לדרגת השלמות (M_c , Magnitude of Completeness) הנמוכה ביותר האפשרית ($M_c < 2$) ו- ג. למזער את המקרים בהם נוצרות רעידות שווא. התחנות הסיסמיות נבחרו על סמך רמות הרעש שלהן, כאשר תחנות עם רעש נמוך יותר מאפשרות לשפר את הליך ואמינות הגילוי. לאחר בדיקת התצורה הסופית שלנו בזמן אמת, הנוהל החדש יושם ב-30 בינואר 2024. אנו מציגים כאן את התצורה והביצועים מתקופת הבדיקה, לאורך חודש שלם, דצמבר 2023. אנו מוצאים שבהשוואה לגלאי הקודם, השיעור היומי של רעידות שווא ירד ב-69%, הגודל המינימלי שזוהה ואושר היה $M1.0$ ודרגת השלמות אותה הצלחנו להשיג היא $M_c 2.2$. המספר הממוצע של אירועים שזוהו באותה תקופה הוא 17 אירועים סייסמיים ביום, עם ממוצע יומי של כ-8% רעידות אדמה מקומיות. צוות האנליסטים שלנו משתמש בזיהויים האוטומטיים כנקודת ההתחלה של עיבוד ידני, על-מנת לספק מידע מפורט על אירועים סייסמיים לבעלי עניין, לחוקרים ולציבור.