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Short Note

Empirically Based Ground Truth Criteria for Seismic Events Recorded at Local Distances on Regional Networks with Application to Southern Africa

by K. B. Boomer, Richard A. Brazier, and Andrew A. Nyblade

Abstract We present a new approach to obtaining empirically based (EB) criteria for estimating the epicentral location accuracy (i.e., ground truth, GT) of seismic events recorded at local distances on a regional network. The approach has been developed using a jackknife resampling method applied to carefully picked Pg phase arrival times for GT reference events from several South African gold mines. The events were well recorded locally by Southern African Seismic Experiment (SASE) stations within the Archean Kaapvaal craton, an area of relatively simple crustal structure. The region-specific criteria obtained specify an EBGT$3_{95\%}$ level of epicentral accuracy if events are recorded on eight or more stations at distances less than the Pg/Pn crossover (215 km) when the stations have a primary azimuthal gap <202 degrees. In addition, when nine or more stations are used for event location and one of them is within 79 km of the event, we find that a focal depth accuracy of 4 km at the 95% confidence level can be obtained and that an accuracy of 6 km can be obtained if eight stations are used. This result illustrates that GT criteria commonly applied to global event catalogs can be relaxed if an accurate velocity model and carefully picked phase-arrival times are used for event locations. Consequently, it is likely that additional events can be added to GT compilations by developing EBGT criteria for other regional networks and using them to identify candidate GT events. For example, the EBGT criteria developed in this study, when applied to the SASE seismicity catalog, yields 10 new GT events.

Online Material: EBGT criteria, new ground-truth events, and validation tables for the Kaapvaal craton.

Introduction

Determining accurate seismic event locations with representative uncertainty estimates is of fundamental importance to ground-based nuclear explosion monitoring, including the assignment of accurate ground truth (GT) levels to routinely located events. The international monitoring community commonly relies on selection criteria for classifying seismic event locations at the GT5 level, which specifies the absolute location error for an event as being less than 5 km. Bondár *et al.* (2001) developed the GT$X_{C\%}$ criteria for specifying location accuracy, where X is the epicenter accuracy in kilometers with a confidence level of C. Bondár *et al.* (2004) and Bondár and McLaughlin (2009) have developed further the GT$X_{C\%}$ criteria using global bulletin data, where the quality of phase picks can be uneven and the velocity model used for event location may not be optimal. Events recorded on regional networks are currently validated at the GT$20_{90\%}$ level (Bondár *et al.*, 2004; Bondár and McLaughlin, 2009).

An inherent restriction when using seismic data from a regional network to identify GT events is that often there are only a small number of recording stations. Both the geometry of the stations in the network and the limited number of stations make it difficult for events located within the network to pass the GT5 criteria of Bondár *et al.* (2004) or Bondár and McLaughlin (2009) and to thus be placed in GT event catalogs, even though the locations could be accurate to within 5 km. In response to this limitation, here we use a statistical resampling technique to empirically develop new GT criteria for classifying seismic event locations from events recorded at local distances on regional networks.

Review of GT Criteria

Bondár *et al.* (2001, 2004) explored the use of network coverage as a metric for assessing location accuracy, where network coverage was quantified by measuring not only the primary but also the secondary azimuthal station gap. They defined the primary azimuthal gap as the largest gap in event–station azimuth for a network and the secondary azimuth gap as the largest gap that results when any given station is removed from a network. The result of their work was a set of selection criteria now commonly used to classify an event epicenter as being accurate to within 5 km (or 20 km) with 95% (or 90%) confidence ($\mathrm{GT5}_{95\%}$, $\mathrm{GT20}_{90\%}$, respectively), hereafter referred to as the 2004 criteria (Table 1).

In developing the 2004 criteria, Bondár *et al.* (2004) aimed to establish conservative estimates of location (epicenter) accuracy by using events from regions with complex crustal structure and by using an average global Pg/Pn crossover distance of 250 km. The rationale for this approach is that simpler geological settings are likely to yield more accurate locations (Bondár *et al.*, 2004). Using bootstrap resampling (with replacement), the locations of four GT0 events were relocated repeatedly. The GT0 events were selected because of the density of station coverage at local distances, with at least three stations within 30 km of each event, and at least 40 stations within 250 km of each event.

Because the 2004 criteria are based on an average global Pg/Pn crossover distance of 250 km, they may not be representative of the local velocity structure and thus may lead to phase identification errors. Recently, Bondár and McLaughlin (2009) have modified the selection criteria using a 150 km Pg/Pb crossover distance to relocate over 90 GT0 events, in part to address the concern over phase identification errors (Table 1). As with the 2004 criteria, the 2009 criteria were developed using events recorded on a large number of local and regional stations with travel times reported in bulletins (Table 2). Bondár and McLaughlin (2009) also simulated sparse networks and selected the 20 most representative network geometries in developing their modified criteria.

Unlike epicenter parameters, focal depth and origin time for an event are strongly dependent on the velocity model used to locate an event. Therefore, the focal depth and origin time cannot be controlled to the same degree of accuracy as the epicenter, and in most GT compilations, event focal depths are not known to 5 km with great confidence (Bondár and McLaughlin, 2009). To ensure that network coverage provides reasonable depth resolution, both the 2004 and the 2009 criteria include a requirement for a minimum distance between a station and the event location (Tables 1 and 2). However, it is important to realize that the GT criteria specify the accuracy of the event epicenter and not the hypocenter.

Background and Data

The Southern African Seismic Experiment (SASE) network ran from 1997 to 1999 and included as many as 116 broadband stations deployed in a swath across southern Africa, primarily within the Archean Kaapvaal craton (James *et al.*, 2001) (Fig. 1). Many of the stations were located within proximity of the deep gold mines around the rim of the Witwatersrand basin in the central part of the Kaapvaal craton (Fig. 1). This area has relatively simple crustal structure that has been well studied and can be adequately represented by a one-dimensional velocity model (Kgaswane *et al.*, 2009 and references therein).

Over the duration of the SASE deployment, many thousand mine-related seismic events were recorded. A catalog of these events, with hypocentral locations good to within a few tens of meters, was provided by the mine network operators (Webb *et al.*, 2001). Data to locate the events came from in-mine networks comprised of two or more horizons of three-component geophones. Because the event locations are accurate to within a few tens of meters, they can be used as GT reference events.

During the SASE deployment, many of the mine-related GT reference events were recorded on over half the 116 stations. However, for any single event, fewer than 15 of the stations were within the local Pg/Pn crossover distance of 215 km; thus, the azimuthal gap coverage among the few recording stations was typically larger than specified by the 2004 and 2009 criteria. Furthermore, none of the events were recorded on a station within 30 km. As a result, none of the events from mine networks meet either the 2004 or 2009 criteria, illustrating the limitations of those criteria.

For this study, five of the larger events recorded on the in-mine networks were selected as reference events for developing regional GT criteria (Table 3; Fig. 2). These events have the following characteristics: (1) recorded on no fewer than 10 SASE stations, (2) event–station distances were less than the local Pg/Pn crossover distance of 215 km, and

Table 1
Global GT Criteria (Bondár *et al.*, 2004)

Network	Distance Range (degrees)	Primary Azimuthal Gap	Secondary Azimuthal Gap	Number of Stations within Specified Distance: Between 250 km and 1000 km	< 250 km	< 30 km	GT level
Local	0°–2.5°	110°	160°	—	10	1	$\mathrm{GT5}_{95\%}$
Near Regional	2.5°–10°	—	120°	10	—	—	$\mathrm{GT20}_{90\%}$
Teleseismic	28°–91°	—	120°	—	—	—	$\mathrm{GT25}_{90\%}$

Table 2

Global GT Criteria (Bondár and McLaughlin, 2009)

			Number of Stations within Specified Distance			
Network	Distance Range (degrees)	Network Metric	Between 150 km and 1000 km	<150 km	<10 km	GT Level
Local	0°–1.35°	<0.35	—	5	1	$\mathrm{GT5}_{95\%}$

(3) the events were magnitude 3.0 or larger. They also come from four different mines.

Methodology

The location of a seismic event using standard methods is calculated based on a regression model using a nonlinear iterative inversion. The regression model is often expressed as

$$t_i = f(\vec{x}_i(\vec{m}), \nu) + \epsilon_i, \qquad i = 1, \ldots, n \text{ stations}, \tag{1}$$

where t_i is the arrival time, $f(\cdot)$ is a nonlinear function of the distance from the epicenter to station i (denoted by the vector $\vec{x}_i$) and a velocity model ν, and the residuals ϵ_i are independent and identically distributed Gaussian random variables with mean zero and common variance σ^2. There are two limitations with this modeling approach. First, independent Gaussian errors are assumed in spite of studies dating back as far as Flynn (1965) that suggest this assumption is unlikely to hold. The magnitude of the errors are likely to vary depending on station configuration and the underlying geological structure, and the distribution of the errors tends to have heavier tails than suggested by the Gaussian model (Buland, 1986). Thus, the associated confidence ellipses, based on a confidence level C, calculated from this model may not be accurate. Second, this model does not take into consideration the geometry of the station array relative to the geology. In the extreme case, recording stations may lie to one side of the event in one geological structure while the event is in a different structure. The 2004 and 2009 criteria are based on station geometry to address this second concern.

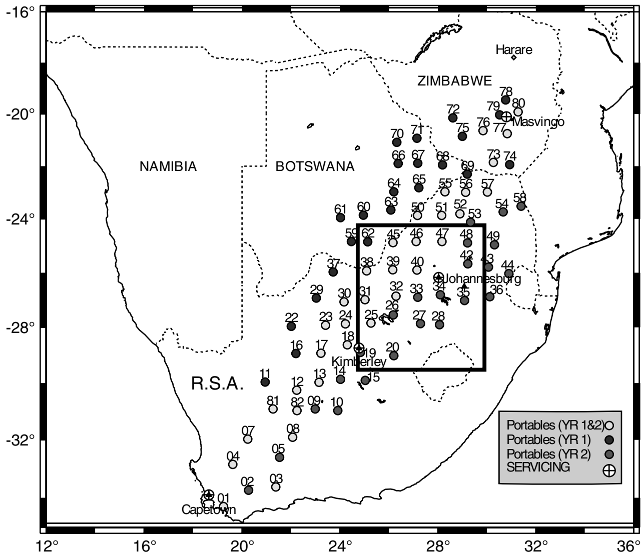

Figure 1. Map showing station locations for the 1997–1999 Southern African Seismic Experiment network. The boxed region is shown in Figure 2. (Figure adapted from Webb *et al.* 2001.)

For estimating location uncertainties, statistical resampling methods provide an alternative to standard modeling methods in which random errors are assumed to have some known probability distribution. In the resampling methods, the available data are used to generate an empirical probability distribution for the true, yet unknown and unspecified, probability distribution (Efron and Gong, 1983). The resampling method often used in developing GT criteria (e.g., Bondár *et al.*, 2004; Yang *et al.* 2004; Bondár and McLaughlin, 2009) is a bootstrap resampling in which $k \le n$ arrival times are sampled with replacement from the set of n available arrival times. This is repeated a large number of times. The 2004 criteria were developed based on a bootstrap sample of $k = 10$ arrival times with 10,000 realizations, where the choice of 10 arrival times was made because requiring a larger number could preclude the use of many smaller networks. Sampling with replacement is used to ensure independent samples, and, particularly when there are a large number of possible elements (e.g., arrival times), a large number of realizations can easily be achieved.

In the SASE network, the larger mine-related events were often well recorded on only 8–13 stations. Therefore, sampling with replacement using $k = 10$ potentially would introduce bias if some stations were included multiple times in each bootstrap sample and others were excluded. Thus, we used a different resampling method, the jackknife method, which relies on sampling without replacement (Quenouille, 1956). This method considers n independent and identically distributed random variables from some unknown probability distribution. The method obtains each of the subsamples of size $n - 1$ from the full set of n observations (i.e., the delete-one method) and, for each subsample, estimates the statistic of interest (i.e., the sample mean) or uses the resulting empirical probability distribution for that statistic to obtain a percentile. The delete-one jackknife has been extended to a delete-k jackknife.

In our regression setting, arrival time data are recorded at n stations, which are used to estimate the location of the event, $\mathbf{x}$. In the jackknife method, data from $k < n$ stations are removed from the full dataset, and the location is recalculated. This is repeated until all subsamples of size $n - k$ have been analyzed (Wu, 1986). An advantage of the

Table 3
SASE Network GT Reference Events

Date (mm/dd/yy)	Origin Time (UTC)*	Latitude†	Longitude†	Depth (km) †	Magnitude †	Number of Recording Stations	Mine
07/27/98	18:56:52	−26.413	27.444	1.234	3.2	10	Western Deep Levels (Tau Tona)
09/19/98	10:32:46	−26.888	26.737	1.393	3.9	11	Klerksdorp
10/02/98	10:17:52‡	−26.395	27.477	0.361	3.8	13	East Driefontein
10/07/98	04:51:06	−26.392	27.492	0.518	3.3	12	East Driefontein
11/19/98	14:07:44	−26.478	27.338	1.154	3.1	10	Deelkraal

*Council of Geosciences, South Africa, catalog provides the most accurate origin times (Webb *et al.*, 2001).
†Local mine catalogs provide the most accurate location, depth, and magnitude data (Webb *et al.*, 2001).
‡International Seismological Centre time 10:20:35.

jackknife estimator over other resampling methods such as the bootstrap is that the variance of the jackknife estimator is robust for nonconstant residual errors in equation 1.

As with the results from bootstrapping, an empirical cumulative distribution plot of the resulting estimated values for the components of **x** gives a data-based probability distribution, from which the ninety-fifth percentile can be obtained to form a one-sided 95% confidence interval for the true epicenter location. It is important to keep in mind that the proper interpretation of a confidence interval (asymptotic or empirical) is that 95% of such intervals are correct in that the true parameter of interest (true event location) is contained within the given interval; 5% of such intervals do not actually contain the true parameter.

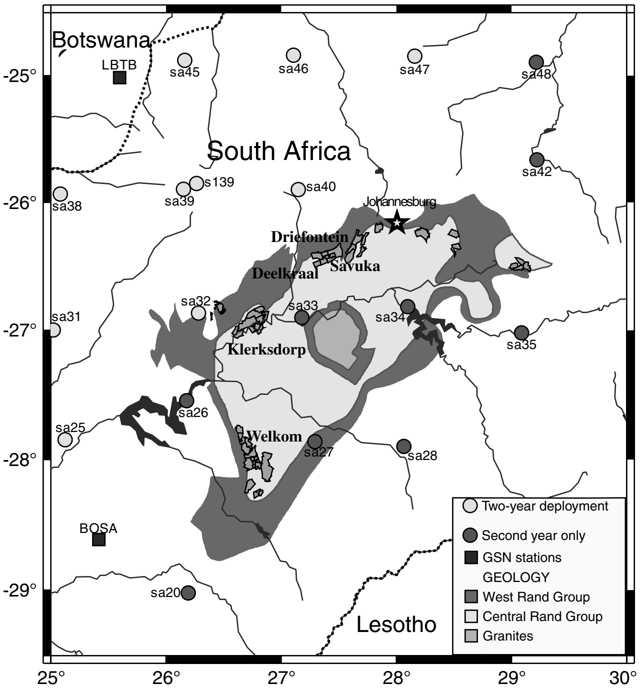

Figure 2. Map showing the geology of the Witwatersrand basin and the locations of gold mines around the margin of the basin, adapted from Webb *et al.*, 2001. SASE stations (circles) used in determining the Kaapvaal EGBT criteria are shown. GT reference events used for the EGBT criteria are located in mines labeled by name. (GSN, Global Seismic Network.)

Application and Results

Pg arrival times, handpicked to an accuracy of 0.5 sec, for the five GT reference events in Table 3 have been used to develop region-specific GT$X_{95\%}$ criteria. Event locations were obtained using the *Pg* arrival times, a 1D velocity model (Table 4), and the HYPOELLIPSE (Lahr, 1989) event location code. The 1D velocity model was obtained from Kgaswane *et al.* (2009), who jointly inverted receiver functions and Rayleigh wave group velocities to obtain 1D crustal models for the SASE stations. The models for the stations shown in Figure 2 are similar and were averaged together to obtain the 1D model in Table 4.

The jackknife method was applied to the five events simultaneously in four separate datasets consisting of all subsamples of (1) 11 stations, $n = 90$; (2) 10 stations, $n = 363$; (3) 9 stations, $n = 997$; and (4) 8 stations; $n = 1988$. For each subsample, the associated event was relocated. Seven subsamples relocated with eight stations had primary azimuthal gaps greater than 202° and resulted in an absolute change in location of > 40 km; these were considered outliers and removed. From this result, we conclude that station geometries with primary azimuthal gaps larger than 202° do not yield accurate event locations. Resampling with subsets of seven or fewer stations resulted in very large primary gaps and/or unrealistic estimates for depths.

Scatter plots in Figure 3 show the absolute epicentral distance change between the event relocation and the GT reference location, plotted versus primary and secondary azimuthal gap. The figure demonstrates that estimated epicentral location changes are less than 3 km, with 95% confidence and that the magnitude of the change in epicentral distance does not increase as the azimuthal gap increases. Intuition might lead one to expect that as the azimuthal gap increases, change in epicentral distance would also increase. This pattern is not observed. The maximum gaps are purely a result of the station geometry and, as the number of stations increase, the geometry will likely have smaller gaps. This finding is consistent with the simple and well-constrained 1D crustal velocity model for the study region.

Shown in Figure 4 are the ninety-fifth percentiles of the empirical cumulative distribution function for change in epicentral distance. Values are less than 3 km for each dataset,

Table 4

1D Velocity Model Used for Event Locations

Crustal Thickness	Average Crustal V_s	Uppermost Mantle V_s	V_p/V_s Ratio
37 km*	3.7 km/sec*	4.6 km/sec*	1.74[†]

*Kgaswane *et al.*, 2009

[†]Nair *et al.*, 2006

indicating that the event locations are $\mathrm{GT3}_{95\%}$ locations. This result, when combined with the primary azimuthal gap determination of 202°, yields a set of empirically based epicentral ground truth (EBGT) criteria for the Kaapvaal craton (Table 5).

A validation dataset was used to test the $\mathrm{EBGT3}_{95\%}$ criteria (Ⓔ see Table S1 in the electronic supplement to this short note), which included 20 additional relocations of GT reference events recorded on at least eight SASE stations within the local Pg/Pn crossover distance of 215 km. These events are either mine-related events or naturally occurring events within the mine network. The events ranged in magnitude from 2 to 4.1 and come from a total of nine mines spread across a larger region than the original five events in Table 3. The events were relocated using handpicked Pg arrival times, and the event locations obtained were all found to be within 3 km of the GT reference location.

To assess the uncertainty in focal depth estimates, we follow the approach taken by Bondár *et al.* (2001, 2004) and Bondár and McLaughlin (2009) and include a minimum event–station distance in our resampling analysis. The stations in the SASE network within and around the Witwatersrand basin were installed roughly 1° apart, and therefore the network geometry dictates that the minimum event–station distance that can always be obtained if all the stations record an event is 79 km. The minimum event–station distance for an event could be less than 79 km but never more than that, given the station geometry. If a relocation subsample were to have a minimum event–station distance greater than 79 km, it would indicate that the nearest station(s) did not record the event. For our dataset, we found that approximately 95% of the relocation samples had a minimum epicentral distance less than 79 km. Using a minimum event–station distance of 79 km, as opposed to the 30 km distance chosen by Bondár *et al.* (2001, 2004) and the 10 km distance chosen by Bondár and McLaughlin (2009), we find that when nine or more stations are used to locate an event, a focal depth accuracy of 4 km at the 95% confidence level can be obtained and that an accuracy of 6 km can be obtained if eight stations are used. Different starting depths throughout the crust produce similar results. Thus our depth estimates are relatively robust and are not likely to be trapped in local minima or be dominated by the location process. Because the 79 km minimum event–station distance results in good control on focal depth, we include that distance in the EGBT criteria shown in Table 5.

Discussion and Conclusion

Our results suggest that the Bondár *et al.* (2004) and Bondár and McLaughlin (2009) criteria are overly restrictive for

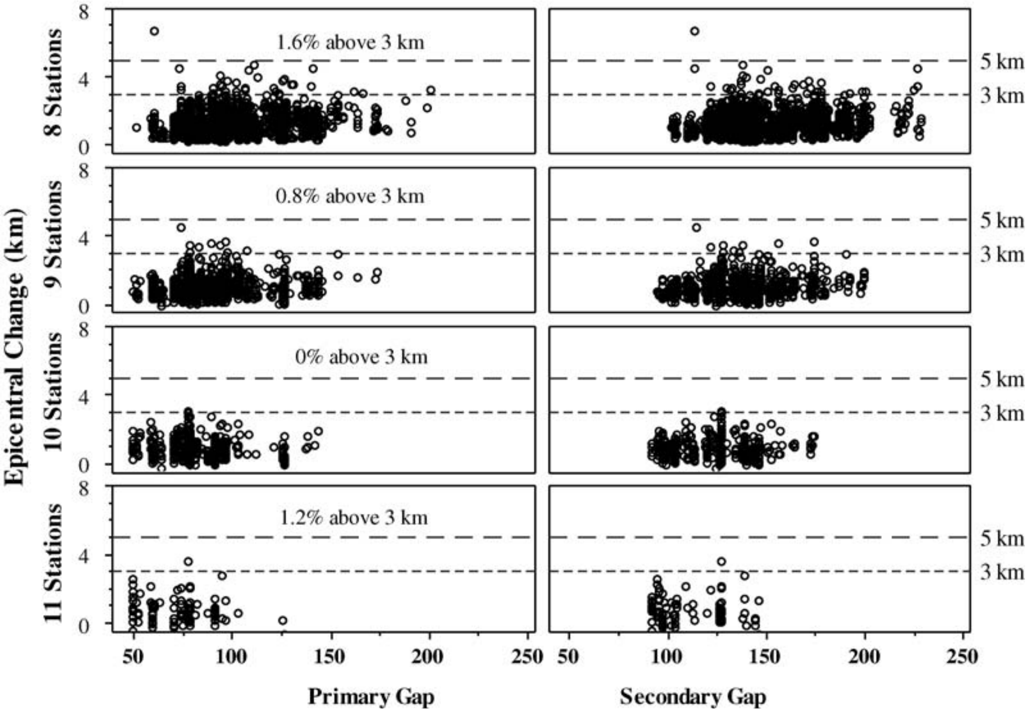

Figure 3. Primary and secondary azimuthal gaps (in degrees) relative to change in epicentral distance for 8 to 11 stations. The GT5 and the GT3 levels are indicated, and the percent of data with changes >3 km is noted.

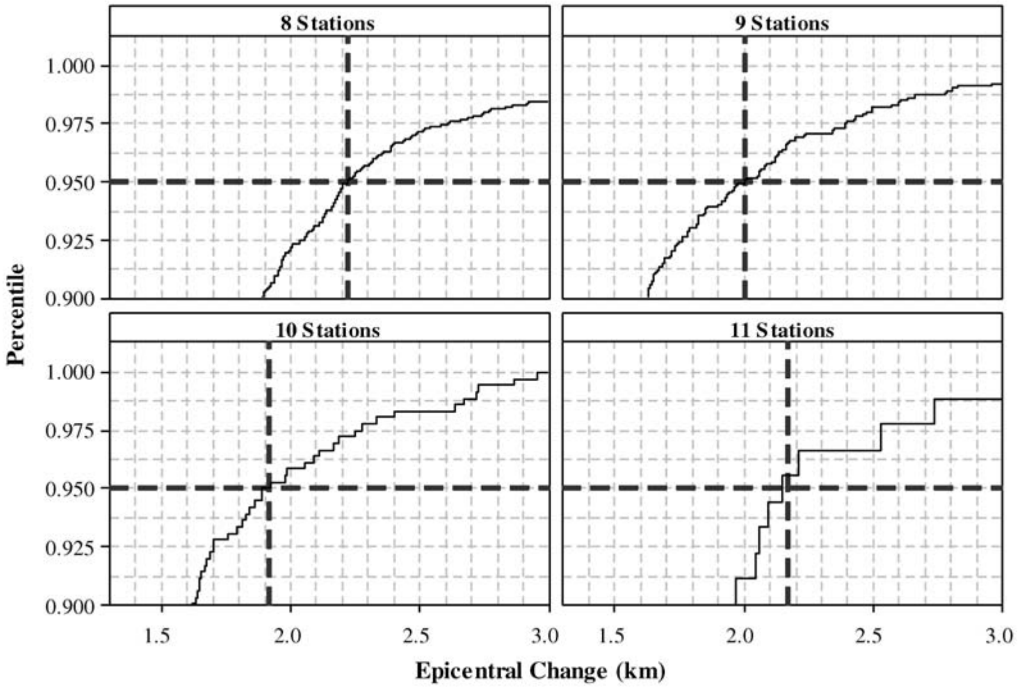

Figure 4. Empirical cumulative distribution functions demonstrating that the ninety-fifth percentile for absolute epicentral change is less than 3 km for each sample.

regional networks, at least for areas with relatively homogeneous crustal structure, as in the case of the Kaapvaal craton in southern Africa. The GT criteria developed for the SASE network indicate that any seismic event on the Kaapvaal craton recorded on eight or more stations at distances of no more than 215 km, all within the Kaapvaal craton, and a primary azimuthal station gap less than 202° meet the $GT3_{95\%}$ level for epicentral accuracy. In addition, having a station at a distance of 79 km or less from the event ensures 4 km accuracy for focal depth when nine or more stations are used or 6 km accuracy when eight stations are used. In comparison to the 2004 and 2009 criteria, there are notable relaxations in our criteria: we require fewer recording stations, none of which need to be within 10–30 km of the event, and the primary azimuth gap can be up to 202°. In our criteria, we also do not specify a secondary azimuthal station gap. Applying the network-specific $EBGT3_{95\%}$ criteria to larger local events in the SASE dataset yields an additional 10 GT3 events (Ⓔ see Table S2 in the electronic supplement to this short note).

Because the EBGT criteria were developed for a network in the middle of an Archean craton where crustal structure is fairly simple, it may be possible to apply the criteria to other areas where the entire network is located in a region with geology similar to the Kaapvaal craton. For example, many of the stations in the 1994–1995 Tanzania Broadband Seismic Experiment (Nyblade *et al.*, 1996) were located in the center of the Archean Tanzania craton, where crustal structure is similar to the Kaapvaal craton (Julià *et al.*, 2005). All but one of the 2000 local events recorded on the Tanzania network failed the 2004 criteria. Applying the Kaapvaal craton EBGT criteria to the Tanzania dataset could possibly yield many $GT3_{95\%}$ events.

The technique outlined in this short note for establishing EBGT criteria for regional networks also can be applied to other datasets from regional networks that contain GT reference events (i.e., mine blasts, shots for refraction profiles, mine events, chemical or nuclear explosions) and, importantly, a well-understood velocity structure for the region

Table 5
EBGT Criteria for the Kaapvaal Craton

GT Level	Number of Stations within 215 km	One-Sided 95% Confidence Interval (km) Epicentral Change	Depth Change	Primary Azimuthal Gap Maximum	Maximum Distance to Nearest Station (km)
$GT3_{95\%}$	11	[0, 2.2)	[0, 0.4)	202°	79
$GT3_{95\%}$	10	[0, 1.9)	[0, 1.8)		
$GT3_{95\%}$	9	[0, 2.0)	[0, 3.8)		
$GT3_{95\%}$	8	[0, 2.2)	[0, 5.7)		

containing the local/regional network. This would possibly increase the number of GT events available to the ground-based nuclear monitoring community. It is anticipated that as the level of complexity increases in crustal structure, the EBGT criteria would become more stringent and at some point converge with the 2004 and 2009 criteria. Additional work on datasets from regional networks with GT reference events is required to further assess the 2004 and 2009 criteria over a range of geologic terrains.

Data and Resources

Seismic waveform data used in this study come from the Southern African Seismic Experiment network and the Global Seismic Network and were obtained through the Incorporated Research Institutions for Seismology Data Management Center. Locations for the GT reference events come from a compilation of event locations based on in-mine network catalogs (Webb *et al.*, 2001).

Ⓔ Tables S1, S2 in the electronic supplement to this short note provide additional information. Table S1 is a list of 20 validation events confirming that the events meeting the EBGT$3_{95\%}$ criteria are indeed all located within 3 km of the reference event. Table S2 includes 10 additional GT events recorded on the SASE network which were previously not classified as GT5 or less events.

Acknowledgments

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Electronic Supplement to

Empirically Based Ground Truth Criteria for Seismic Events Recorded at Local Distances on Regional Networks with Application to Southern Africa

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Table S1. New $GT3_{95\%}$ Events from the Kaapvaal Craton recorded on the SASE Network

Date	Time	Latitude	Longitude	Depth (km)	N	Minimum Distance (km)	Primary Gap (deg)	Magnitude	Change in Epicentral Distance (km)
04/26/98	00:50:26	-26.370	27.492	0.1	8*	62*	141*	3.4	1.46
05/09/98	11:56:58	-26.898	26.761	2.6	9*	42*	83	3	2.51
05/21/98	16:13:29	-26.966	26.786	5.2	10	40*	70	3.2	1.45
06/17/98	12:50:22	-26.398	27.501	0.0	13	64*	49	3.1	1.48
07/29/98	05:34:04	-28.062	26.805	10.6	10	53*	127*	3.0	1.86
08/05/98	13:20:27	-28.023	26.825	15.3	9*	49*	125*	3.1	1.80
08/21/98	16:10:55	-26.949	26.767	5.9	10	41*	68	3.8	0.62
09/01/98	11:18:32	-28.062	26.849	12.6	10	49*	129*	3.1	1.42
09/10/98	06:34:55	-26.412	27.605	1.4	10	65*	131*	2*	1.81
09/10/98	16:15:22	-26.383	27.609	0.8	11	67*	81	2.7*	0.92
09/11/98	17:50:48	-26.407	27.600	0.0	11	66*	79	2.4*	1.93
09/18/98	14:12:34	-28.017	26.756	9.5	11	56*	122	3.3	0.65
09/18/98	12:52:26	-28.013	26.754	11.5	10	56*	121*	3.1	0.91
09/25/98	15:51:33	-26.926	26.805	6.8	11	37*	67	3.9	0.11
11/17/98	20:18:01	-26.925	26.781	5.8	9*	40*	67	3.8	1.08
11/18/98	16:30:07	-26.956	26.786	9.2	8*	40*	71	3.9	1.29
11/27/98	23:52:34	-26.981	26.759	0.0	8*	43*	71	3.2	0.99
12/01/98	18:12:17	-28.013	26.760	11.9	8*	55*	134*	3.1	1.27
12/05/98	04:52:46	-26.364	27.602	0.0	9*	69*	125*	3.8	1.14
12/16/98	16:00:04	-26.403	27.434	0.5	8*	61*	93	3.3	1.1

Notes:

*= Does not meet the 2004 or 2009 criteria

N = Number of recording stations

[Back]

Electronic Supplement to

Empirically Based Ground Truth Criteria for Seismic Events Recorded at Local Distances on Regional Networks with Application to Southern Africa

by K. B. Boomer, Richard A. Brazier, and Andrew A. Nyblade

Table S2. New $GT3_{95\%}$ Events from the Kaapvaal Craton recorded on the SASE Network

Date	Time	Latitude	Longitude	Depth (km)	N	Minimum Distance (km)	Primary Gap (deg)	Magnitude
07/25/97	23:33:56	-25.461	27.612	11.2	9	67	181	3.1
04/26/98	0:50:26	-26.369	27.49	0.0	8	62	141	4.1
06/19/98	11:47:50	-28.033	26.877	11.4	9	45	128	4.3
06/22/98	17:48:22	-26.437	27.441	0.0	13	57	51	2.5
06/27/98	23:19:31	-26.484	27.372	0.1	13	50	54	2.6
07/27/98	12:40.00	-26.146	29.218	0.3	8	53	86	4.0
09/16/98	07:03:01	-28.115	26.877	11.8	10	50	135	3.7
10/08/98	22:44:02	-25.645	27.337	0.0	12	34	58	3.2
11/17/98	14:01:53	-26.432	27.450	0.1	11	58	73	2.5
01/07/99	10:41:33	-29.509	24.960	8.8	8	76	187	2.7

[Back]