SEISMICITY RATES IN EASTERN AUSTRALIA

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ABSTRACT

A process has been developed that corrects an earthquake catalog for variations (in both time and space) in network detectability. This approach has been applied to a catalog of earthquakes in eastern Australia to provide the first quantitative, unbiased comparison of seismicity parameters across the region.

Seismicity b-values were determined for large (typically 150,000 km^2) areas and were seen to vary between 0.68 and 0.92. There was no observable systematic dependence on tectonic or geographical parameters, but there was a tendency for higher b-values to be associated with lower A_0 values.

Seismicity rates (A-values) for the region, calculated on 0.5 degree (~50km) squares, show that regions of higher seismicity correlate well with the locations of larger (M>5) earthquakes.

1. INTRODUCTION

Catalogs of instrumentally recorded seismicity are strongly influenced by variations (in both time and space) of the instrumental network. The effects of these variations must be removed in order to obtain a picture of the true seismicity. Cuthbertson (2006) developed a methodology to perform the appropriate corrections to an earthquake database and applied it to eastern Queensland. This paper extends that analysis to include all of eastern Australia.

Reliable and stable estimates of seismicity rates require a significant number of earthquakes – typically hundreds but preferably thousands. In Australia the relatively low seismicity rates and the poor level and relatively short duration of earthquake monitoring mean that the only way to obtain the required number of earthquakes for reliable estimates is to consider large areas. The analysis is then seriously compromised by variations in network detection capability across that area. The solution is to divide the area into smaller zones (so as to reduce variability in space), correct each area for variability in time, and then sum the results to obtain an estimate of seismicity for the entire area.

In this paper all rates are expressed as the annual number of earthquakes greater than a particular magnitude in an area 100 km by 100 km.

2. DATABASE COMPLETENESS

The level of completeness of an earthquake catalog can be defined as the minimum magnitude above which all of the earthquakes in a given space-time volume have been located. While some earthquakes below the level of completeness may be located, not every one will be. This magnitude threshold will vary both in time and in space.

Spatial variation will occur because a seismograph network will only be able to record small earthquakes if they occur close to a seismograph. Earthquakes from outside a network or where the network has a large station spacing will only be recorded if they are of a larger magnitude.

Temporal variation of the magnitude detection level will occur when networks are installed and removed, when instrumentation is changed and even when operating or analysis procedures are altered.

3. NETWORK DETECTION CAPABILITY

In this study the ability of a seismograph network to detect an earthquake was based on the operating period of each seismograph together with a subjective *quality factor* for each seismograph. The *quality factor*, which indicates the ability of a seismograph to record an earthquake, was subjectively assigned based on the instrumentation that was installed (seismometer or accelerometer), the noise level at the site and the recording technique used (continuous or triggered).

The *quality factor* was then converted to a detection function (magnitude versus distance) based on an attenuation function appropriate for the area. In this study, the three levels of *quality factor* were simply equated to three levels of acceleration based on the attenuation function used in Rynn (1987). In this manner the history of the seismograph network was used to calculate the variation in detection capability at every point at any time.

4. THEORETICAL AND ACTUAL DETECTION CAPABILITIES

The theoretical detection curves determined using the above technique were compared with the actual performance of a number of seismographs operated by ES&S. Over 13,000 arrival times were extracted from the ES&S eqSuite database and compared with the earthquakes recorded over the same period (1999 to 2007). This comparison was only performed on arrivals from digital seismographs operated by ES&S so is of limited value. However it is presented so as to compare the theoretical and actual detection capabilities.

The analysis compares the <u>actual</u> recorded arrivals with the arrivals that <u>could</u> have been recorded (based simply on the earthquake database and the seismograph operating period). The percentage of recorded arrivals versus potential arrivals are plotted with respect to magnitude and distance in a similar manner to Schorlemmer and Woessner (2006).

Schorlemmer and Woessner used data from 63,000 earthquakes recorded at 421 stations in California. This study had typically less than 300 arrivals for any one station and so a revised strategy was adopted. Rather than calculating percentages based on ranges of magnitudes and distances, the cumulative total for all shorter distances and all higher magnitudes was plotted. This procedure made the results more stable.

An additional procedure was adopted whereby the calculated cumulative percentages were automatically increased if the percentages either at lower magnitudes or at longer distances were higher. That is, it was assumed that the percentages would always increase as distances became shorter and magnitudes became higher. This further increased the stability of the results.

Figure 1 shows results for one station (MLW). Actual arrivals are shown as open circles while potential arrivals are shown as crosses. Percentage contours of recorded versus all potential arrivals, obtained using the two procedures described above, are also shown.

No attempt was made to ascertain why a seismograph did not record an arrival that was well within its capability. Presumably the majority of these unrecorded arrivals were due to the instrument being inoperative. While the performance curves could be corrected for these inoperative periods, this would then require that the actual seismograph history file include ALL inoperative periods. This was seen as an unnecessary and complicated second-order correction to the original simple approach.

Figure 2 shows results for stations that had over 200 arrivals (total of six stations). Only the 90% contour for each site is shown. The three thick grey lines are the three detection curves defined by the seismograph *quality factors*. The three continuous sites at seismically quiet sites (CDN, CCR and TOM) should correspond with the lowest detection curve (best detection capability). MLW should correspond with the middle

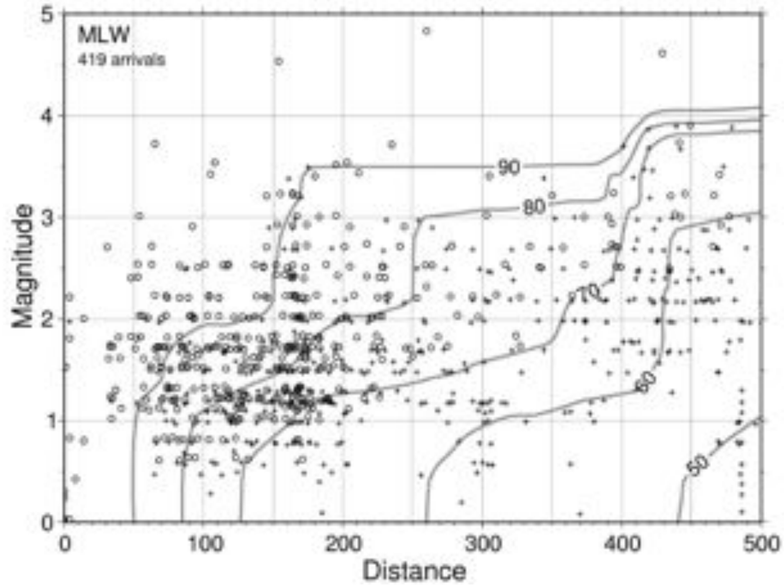

Figure 1:Detectability plot for a single station (MLW).
Circles - recorded arrivals. Crosses - arrivals that were not recorded.
Numbers indicate cumulative percentages of recorded versus unrecorded arrivals.

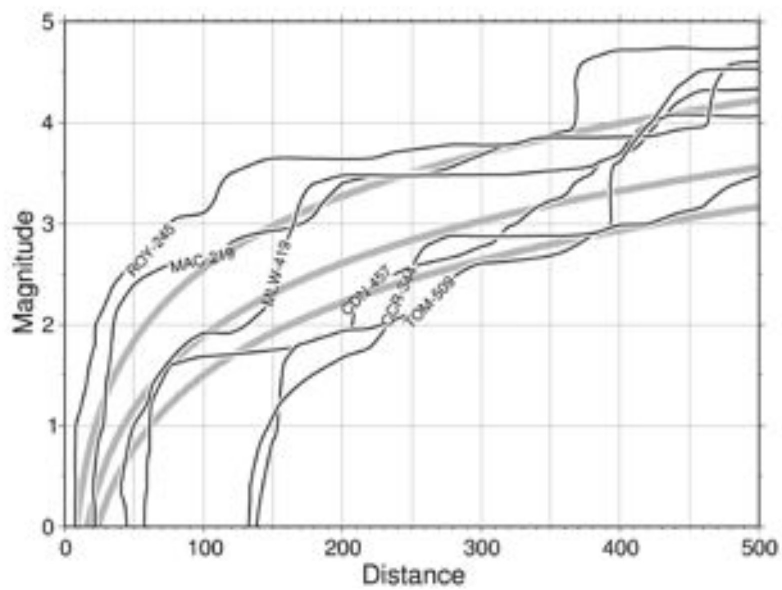

Figure 2:Detectability plots(90% contours) for stations with over 200 recorded arrivals.
Numbers on lines indicate number of arrivals detected.
Grey lines are detection curves corresponding to seismograph "quality factors".

curve (for a triggered site). ROY and MAC are both seismically noisy and should correspond with the uppermost detection curve (poorest detection capability).

In some cases the 90% curves matched or exceeded the detection curve that was used for triggered digital seismographs. The fact that some exceeded the theoretical curve is not of concern – this will simply mean that some earthquake may be ignored when they could have been included. This will not affect the calculated rates – it will only reduce the number of earthquakes being considered.

This brief analysis indicates that the theoretical curves match reality at least to the first order. While a more sophisticated algorithm could be used to calculate network detection capability it is considered that the current simple method is adequate.

5. METHODOLOGY

The recorded seismicity is partitioned into a grid of squares 0.5 degree (~50 km) on each side. This choice of size is a balance between a small-sized square which will not have any variation in detection level within it but will contain few earthquakes, and a large-sized square which will encompass more earthquakes but within which the detection level may vary significantly.

Earthquake rates in each square are calculated by only considering events that occurred above the detection threshold and correcting for the length of time that the magnitude being considered was above the detection threshold for that square. The rates calculated for each square are then summed with neighbouring squares to provide more reliable estimates of seismicity.

6. DATA

The earthquake database used in this study was provided by Gary Gibson. It covers eastern Australia (longitude 136˚ to 158˚ east, latitude 10˚ to 48˚ south) and contains information from all known earthquake databases for the area. The seismograph database was combined from various sources and edited to exclude duplications and to correct obvious errors in operational periods. The analysis software calculated network detection capabilities for the central point of each 0.5 degree square for one-month intervals from 1900 to 2006.

7. SEISMICITY b-VALUES IN EASTERN AUSTRALIA

The following analysis assumes that the number of earthquakes (N) above a particular magnitude (M) is described by the linear Gutenberg-Richter relationship:

$$\log(N) = \log(A_0) - bM$$

where A_0 and b are parameters that describe the seismicity rate in an area.

Accurate calculation of the two parameters, A_0 and b, requires at the minimum several hundred events. In Australia, because of the low seismicity levels and the short instrumental record, the required amount of data can only be obtained by considering a relatively large area.

Seismicity b-values in eastern Australia were calculated by analysing the recorded seismicity in areas that ranged from 20,000 to 850,000 km^2, but were typically about 150,000 km^2. Areas were chosen based mainly on the level of recorded activity; being made large enough so that they encompassed enough data to give a reliable b-value estimate. Data within each area was analysed on a 0.5 grid to correct for variations in network detection capability. An example of the analysis performed is presented in Figure 3 for an area in southeast Queensland. Seismicity b-values were automatically fitted using both maximum likelihood and least squares methods.

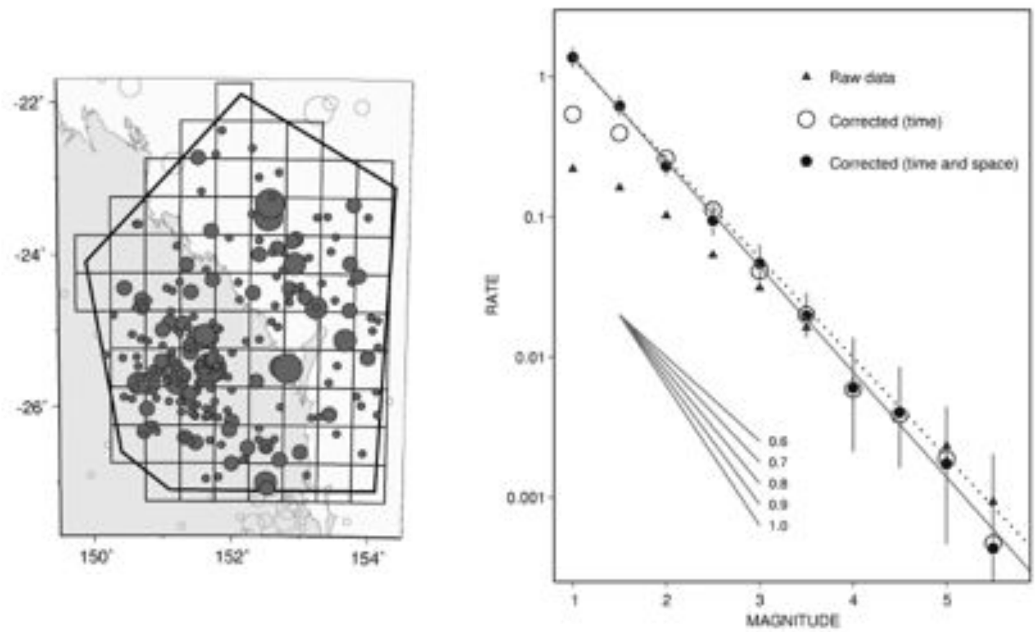

Figure 3:Magniutude-recurrence analysis for an area of southeast Queensland. Zone and sub-zones on the left, raw data and corrected recurrence rates on the right. Dashed and solid lines are maximum likelihood (b=0.68) and least squares (b=0.76) estimates respectively of the b-value.

The maximum likelihood estimate (MLE) (Aki 1965, Utsu, 1965), in providing equal weighting to all earthquakes, is the statistically correct approach for estimating b-values. However, the approach assumes that errors are distributed uniformly among all earthquakes, which will not be the case if the minimum magnitude of completeness is in error. Because the MLE method assigns uniform weights to every earthquake, and because there are many more earthquakes at lower magnitudes, this method can be seriously compromised by errors in completeness calculations.

In Figure 3 the MLE produces a line that is above all but one of the data points (at magnitude 1.5) of rates (corrected for time and space). The large weights assigned to the points at low magnitudes (because of the large number of earthquakes) skew the b-value estimate such that the rates at higher magnitudes are consistently overestimated. It is the rates at these higher magnitudes which are of the most importance for hazard analysis.

Simple least squares estimation provides equal weighting to each rate at each magnitude. While this approach can lead to unrealistic calculated b-values because of the large variability in rates at higher magnitudes it is felt that in most instances it provides a satisfactory fit to the data.

Figure 4 shows the results of the analysis for selected zones. The rates have been normalised so that a b-value of 0.8 is horizontal. This normalisation accentuates deviations from linearity and allows for easier comparison between zones.

Seismicity b-value estimates determined using least squares ranged from 0.68 to 0.92 (for all but one of the 19 zones for eastern Australia). The errors brought about by the large uncertainties in the rates at higher magnitudes (due to a scarcity of events) make it difficult to determine an accurate b-value. However it is felt that the variation in b-values determined from this analysis is indeed real.

No systematic geographic variation in b-value in eastern Australia could be ascertained although there was a tendency for higher b-values to be associated with lower A_0 values.

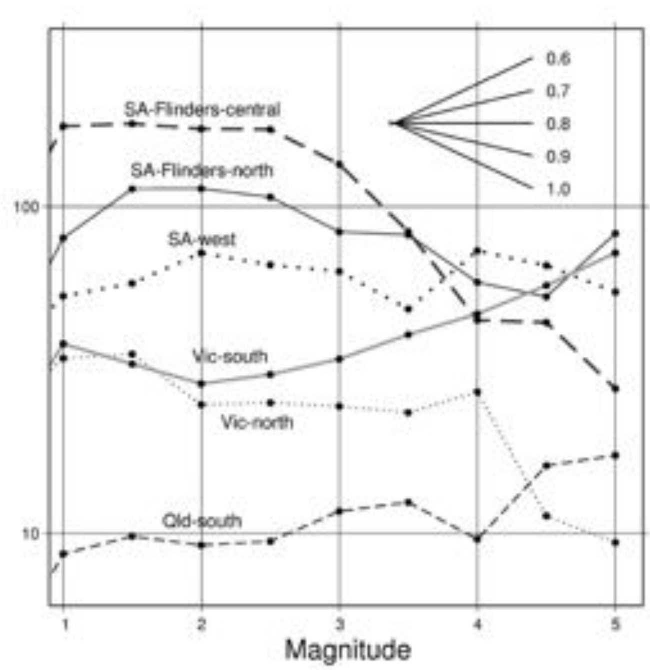

Figure 4: Magnitude-recurrence plots for selected zones. Rates have been normalised so that a b-value of 0.8 is horizontal. The vertical scale is then only a relative indication of rates.

The one zone with a b-value outside the range stated above was in the central Flinders Ranges, South Australia (see Figure 4) with b=1.02. The areas to the south and north showed more normal values so it is unlikely that the anomalous value is a result of the analysis technique or of errors in the database. A plot of earthquakes versus time for the zone shows a dramatic reduction in the rate of magnitude 4^+ earthquakes over time – with 11 occurring in the 80 years prior to 1965 and only one occurring in the 40 years since. This clustering in time, while not unbelievable, does seem unusual.

8. SEISMICITY RATES IN EASTERN AUSTRALIA

To study the variation in seismicity levels across eastern Australia, the calculated rates within each 0.5 x 0.5 degree square were fitted with a line with a b-value obtained from the above analysis. These rates were then smoothed and contoured. Only squares containing three or more earthquakes and with non-zero rates were considered. Figure 5 is a map showing the A-values for eastern Australia for magnitude 5^+ earthquakes.

Regions of higher seismicity correlate well with the locations of larger (M>5) earthquakes. Note that this analysis technique does not just use the large earthquakes to determine the rates - rates from as many magnitude ranges as possible are utilized – although it is not surprising that there should be some correlation between large earthquakes and higher seismicity rates.

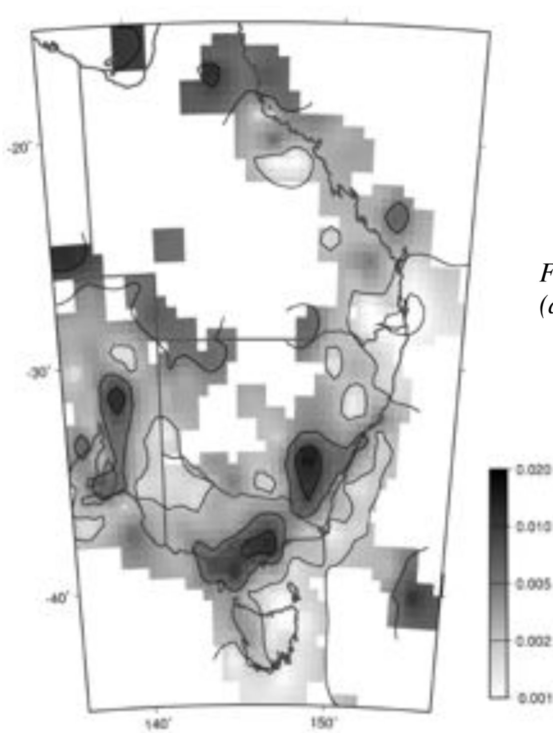

Figure 5: Seismicity rates for magnitude 5^+ (annual number of earthquakes per 10,000 km^2).

9. SUMMARY

A simple approach, using the seismograph network operating history together with estimates of the performance characteristics of each site, can provide reasonable estimates of seismicity values that are corrected for variations in network detectability.

The seismicity rates for eastern Australia, determined using this approach, provide the first quantitative, unbiased comparison across the region. Regions of higher seismicity correlate well with the locations of larger (magnitude 5^+ earthquakes).

Seismicity b-values in eastern Australia are shown to vary between 0.68 and 0.92 with no observable systematic dependence on tectonic or geographical parameters.

10. ACKNOWLEDGEMENTS

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