Towards Improving M_L Estimates for Local Earthquakes Made by Geoscience Australia's Earthquake Monitoring System

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Abstract

Here we undertake a statistical analysis of local magnitudes (M_L) calculated using the two real-time earthquake monitoring software platforms used by Geoscience Australia (GA) since 2005, Antelope and SeisComP. We examine a database of just over 10 years duration, during a period in which both systems were in operation and over 4000 earthquakes were located and magnitudes estimated. We examine the consistency of both single-station and network M_L estimates of both systems, with a view toward determining guidelines for combining them into a single catalogue, as well as for determining best practice for estimation of local magnitudes for regions of sparse seismic networks. Once this guidance has been developed, it is the intention of GA to re-process magnitudes for all earthquakes using a consistent approach where digital data are available and can be integrated within the currently-used SeisComP system.

Keywords: earthquake, earthquake catalogue, earthquake magnitude, Australian seismicity.

1 Introduction

Geoscience Australia (GA) routinely estimates magnitudes for Australian earthquakes, for the purpose of providing real-time alerts, and for building an earthquake catalogue that may be used for seismic hazard assessments. For over two decades, GA's magnitudes have estimated local magnitude (ML) based on region-dependent formulae developed in the 1980s and 1990s. During this time GA has moved from using an internally developed earthquake monitoring system (pre-2005) to utilizing off-the-shelf systems of Antelope (2005-2018) and SeisComP (2018-present). Over time, these systems have used different algorithms for event review and magnitude estimation. As part of a long-term effort to improve the consistency of catalogue magnitudes, GA is undertaking a review of these past magnitude estimates and identifying ways in which they could be improved. This work began with the assembly of a waveform database of over 4,000 earthquakes processed by the Antelope system from 2011-2018 (Figure 1). These events are then processed using both SeisComP and research codes written specifically for this study, applying the regionalised ML formulae.

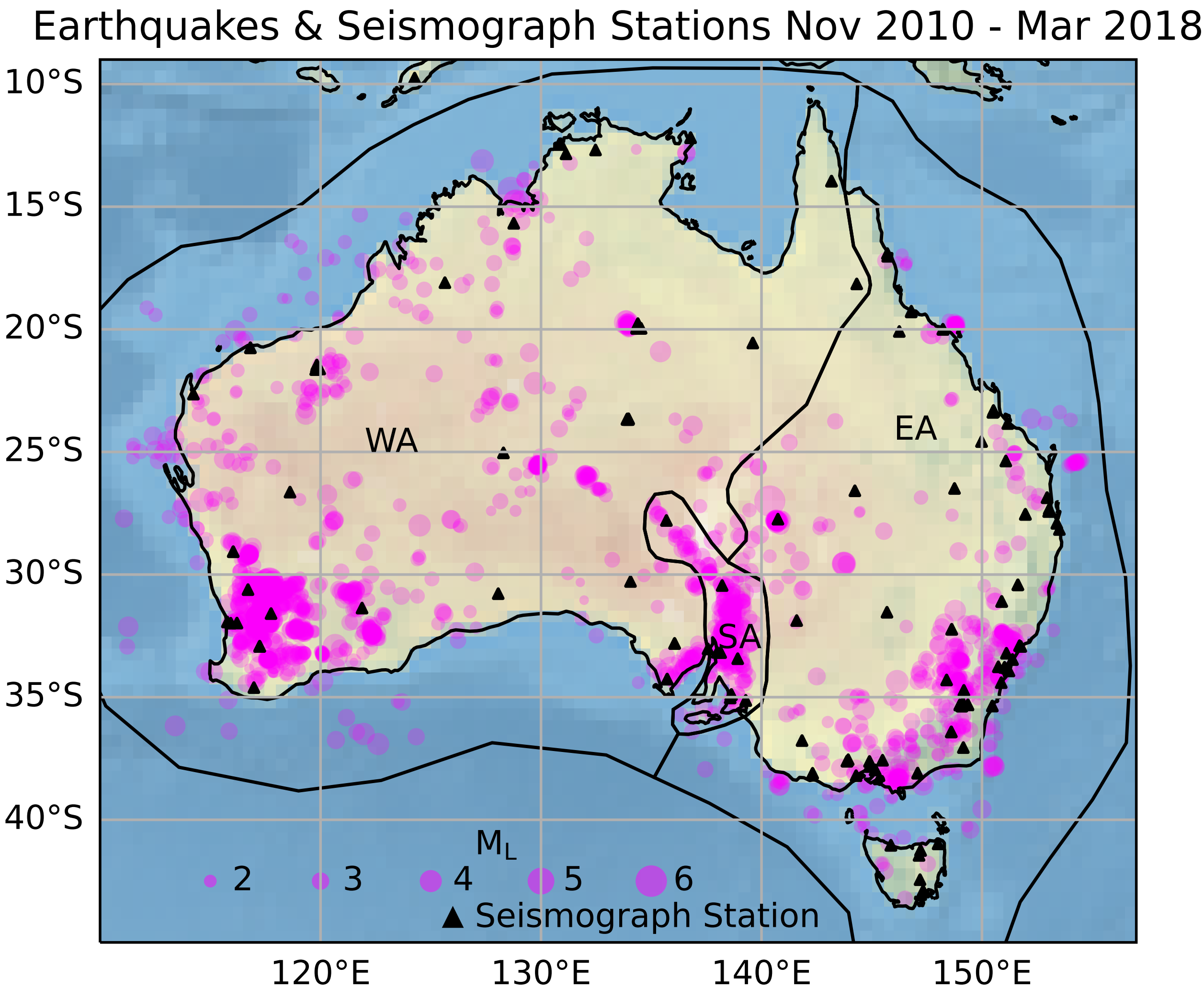

Figure 1. Australian earthquakes for which local magnitudes were estimated by both the Antelope (real-time) and SeisComP (retrospective) earthquake monitoring systems, between Nov 2010 and Mar 2018. Magenta circles indicate earthquake locations and are scaled by magnitude, black triangles show seismograph station locations, and polygons indicate where different magnitude formulae regions are used for western, eastern and southern Australia (WA, EA and SA, respectively).

2 Antelope vs. SeisComP M_L Comparison

Since 2005, GA has adopted two widely-used and well-established software platforms for automated, real-time earthquake monitoring: first Antelope, a commercial package created by Boulder Real-time Technologies (www.brtt.com), and later SeisComP, an initially public-domain software package now commercially supported by Gempa (www.gempa.de). See Pesaresi (2011) for a description and comparison of these packages. A catalogue of Antelope event data (magnitudes, picks, etc) was available for the period November 2010 to March 2018, during which time over 4,000 earthquakes and 1,000 quarry blasts were detected and located. The available waveform data for this period were re-processed with SeisComP, using exactly the same configuration as GA's real-time SeisComP system. Of the events present in the Antelope database, just over 2,700 had at least four station magnitude estimates common to both the Antelope and SeisComP systems, which is the minimum deemed adequate for a reliable network magnitude estimate. These events and the seismographic stations for which station magnitude estimates were calculated are shown in Figure 1.

Both Antelope and SeisComP allow for configurable estimates of local magnitude (M_L). During the time Antelope and SeisComP have been used, GA has used the regionalisation indicated in Figure 1, so that the local magnitude formula of Gaull and Gregson (1991) is used in the polygon denoted WA in Figure 1, while that of Michael-Leiba and Malafant (1992) is used for earthquakes in EA and that of Greenhalgh and Singh (1986) is used in SA. Like the original M_L formula of Richter (1958), all of these formulae express magnitude as a function of the maximum displacement that would be measured on a Wood-Anderson (W-A) seismograph, and the distance (hypocentral distance for Gaull and Gregson, 1991, and Michael-Leiba, 1992, and epicentral distance for Greenhalgh and Singh, 1986) of the station from the earthquake. While the original Richter (1935, later modified in Richter, 1958) formula was based on the maximum horizontal amplitude on an actual W-A instrument, the three Australian formulae use the maximum vertical amplitude of a seismogram that has been converted to W-A displacement using digital filtering. The formula developed by Greenhalgh and Singh (1986) was based on data recorded within an epicentral distance of 500 km, while that of Gaull and Gregson (1991) and Michael-Leiba (1992) fit data to 2000 and 1500 km, respectively. The SeisComP software applies a distance range cut-off of 11°, and that has been used here for both Antelope and SeisComP M_L estimates.

Although both of these systems should produce identical results, there are differences in the resulting M_L estimates due to the differences in the implementation of the magnitude algorithm – e.g., the length of time window used, the method used to calculate maximum Wood-Anderson amplitude, waveform pre-filtering and signal-noise parameters. Ongoing work being undertaken in parallel to this study is exploring the magnitude sensitivity due to the application of alternative pre-filtering, signal-noise parameters and duration windows. The end goal of this parallel study is to ensure catalogue magnitudes are unbiased given the factors listed above.

Figure 2 displays a comparison of Antelope vs. SeisComP station M_L estimates, subdivided by earthquakes with epicentres in each of the three magnitude regions. Histograms of the differences between the two estimates shows that the vast majority lie within 0.1 magnitude units of the mean. However, this mean is shifted by about -0.1 units, indicating that SeisComP M_L estimates are systematically higher than those of Antelope. Furthermore, a few stations appear as outliers having particularly large differences between Antelope and SeisComP. In addition, these differences exhibit more spread for Western Australia than for the other regions. In particular, station KLBR in Western Australia appears to consistently produce SeisComP M_L estimates about 0.5 units larger than those of Antelope. We note that some of these differences may reflect differences in prefiltering and/or instrument response information, and for Antelope this legacy information is currently unavailable.

Single-station M_L estimates calculated with Antelope vs. SeisComP may highlight how subtle differences in processing can result in significant differences in estimated M_L. However, it is important to also consider how these estimates may affect the network M_L estimates that are eventually entered into the catalogue. SeisComP calculates a network M_L whenever at least four station M_L estimates are available for an event, in which case the network M_L is calculated as the median of the single-station magnitudes. Use of the median results in a more robust estimate of M_L that is less sensitive to large single-station outliers than the mean would be.

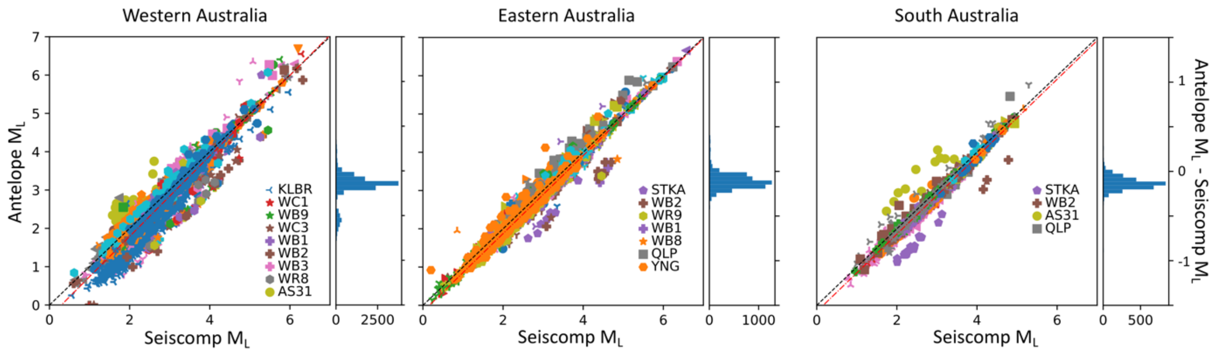

Figure 2. Antelope and SeisComP single-station M_L estimates for the three different regions. Each station is plotted with a distinct colour/symbol combination, and these combinations are indicated for selected stations in each region. Only station names that appear as significant outliers are labelled. For each region, the panel at right shows the distribution of Antelope vs. SeisComP single-station M_L estimates.

Figure 3 (upper panels) presents a comparison of network local magnitudes calculated using Antelope vs. those calculated by SeisComP for the three regions. As expected, the scatter in the distribution of these differences is less than it was for the station residuals, but the peak of the difference distribution indicates that the SeisComP network magnitudes are biased to higher values than the Antelope, by about 0.1 magnitude unit. As with the single-station M_L estimates, the difference distribution for the Western Australia region is wider than those for the other regions, although the -0.1 magnitude unit bias is similar.

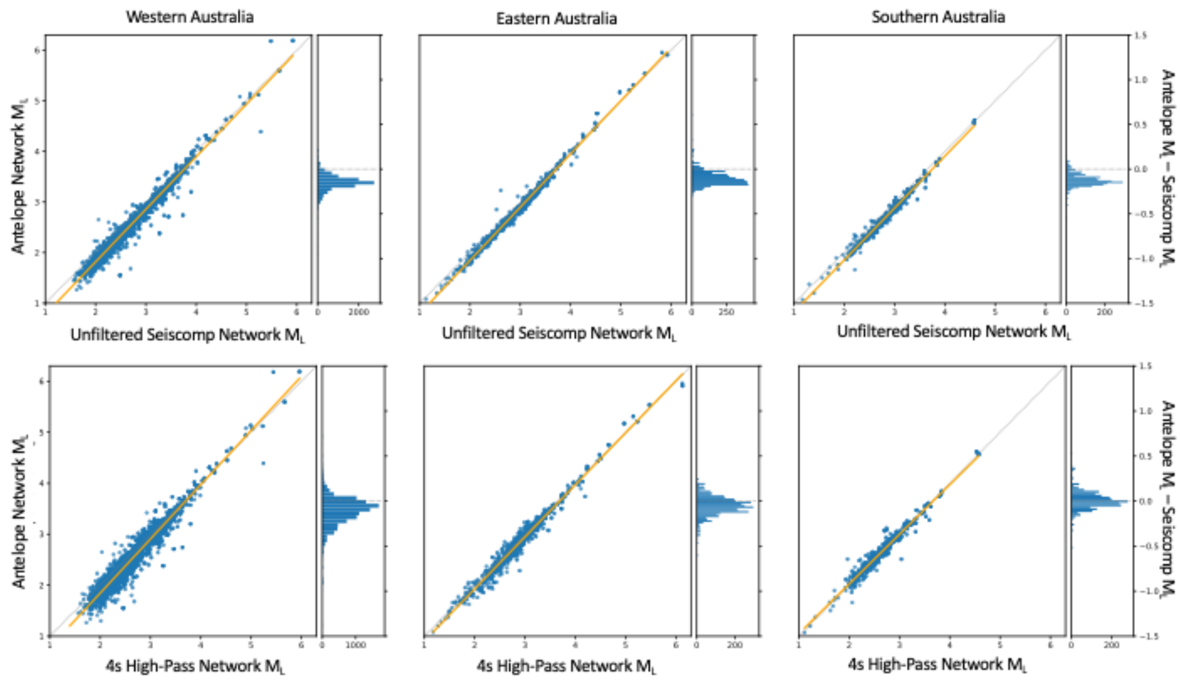

Figure 3. A comparison of network magnitudes calculated by Antelope and SeisComP for the three regions of Australia. Blue circles denote the Antelope vs SeisComP network M_L values for each event, grey lines indicate equality of these values, and the orange line is the result of linear regression between the two. Panels to the right of each scatter plot show histograms of the corresponding network M_L differences. The upper panels are for unfiltered data, while the lower three panels show results where the x-axis magnitudes have been calculated with data high-pass filtered at 4.0 s.

3 High-pass Prefiltering to Improve M_L estimates

The database of Australian earthquakes used here is dominated by events with $M_L < 3.5$, and the vast majority of station epicentral distances are greater than 100 km. For small events observed at large distance, the signals are likely to be weak. In particular, it seems likely that low-frequency noise may bias the W-A displacement measurements, even though the W-A response is less sensitive to periods longer than 1 s. We tested this hypothesis by high-pass filtering the waveforms before convolving with the W-A response.

The lower panels of Figure 3 display comparisons the of Antelope-calculated network M_Ls with those calculated using waveforms high-pass filtered at 4.0 s. For the western and eastern Australia regions, this has largely removed the -0.1 magnitude unit bias with respect to the Antelope M_Ls, at the expense of a slightly wider difference distribution. The bias has not been completely removed from the Western Australia results, for which the difference distribution is again wider than it is for the other regions. Does this result imply that the high-pass filtered waveforms produce better single-station M_L estimates than the unfiltered waveforms? We were unable to ascertain whether the Antelope-calculated M_Ls used prefiltered data, so we don't know why the prefiltered results are more consistent with Antelope estimates.

To ascertain whether the high-pass prefiltering produces better *internal* consistency, we compared station M_L residuals – the difference between single station and network M_L estimates, for Antelope M_Ls versus those calculated in this study using unfiltered and high-pass filtered (at 4.0 and 2.0 s) waveforms. Antelope station M_L residuals were calculated using Antelope network M_Ls, while residuals for filtered and unfiltered data were calculated using network M_Ls calculated using each respective waveform dataset. Such a comparison for seismograph stations in the eastern Australia region is shown in Figure 4. The station M_L residuals appear to be very similar for all of these datasets. There are some marginal improvements to some station residuals for the 4.0 s high-pass filtered results, but some stations actually have a wider spread of residuals for the 2.0 s high-pass filtered results.

In summary, while high-pass filtering waveforms seems likely to improve the agreement between MLs calculated using SeisComP and Antelope, it is not clear whether high-pass filtering improves the actual M_L estimate in any other way.

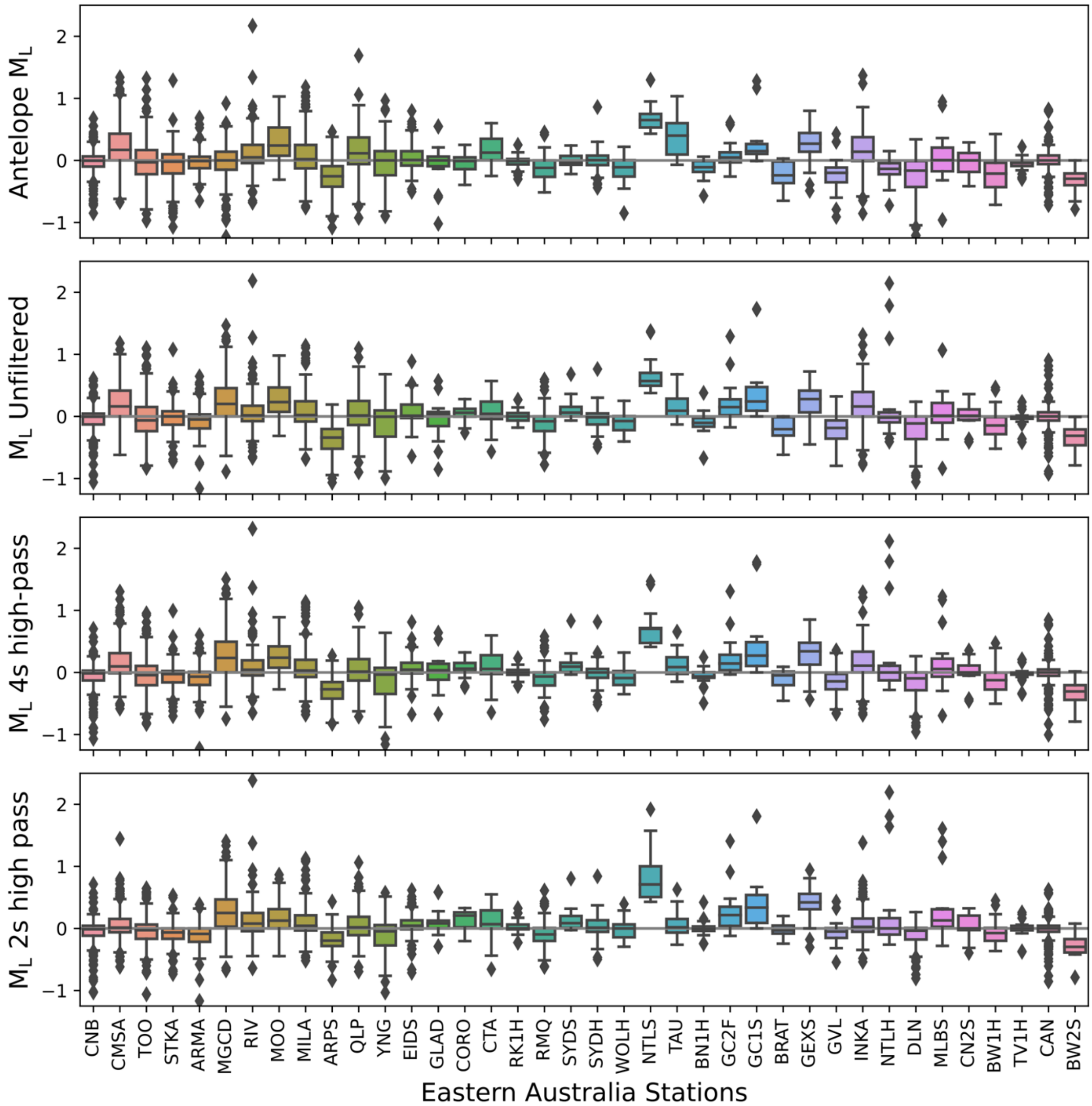

Figure 4. Comparison of station M_L residuals – single-station M_L minus the corresponding network M_L – for seismograph stations in the eastern Australia region, for M_L estimates made using Antelope, unfiltered waveforms and waveforms high-pass filtered at 4 and 2 s (top to bottom panels). The filtered waveforms were processed using a standalone code with M_L implementation very similar to that of SeisComP. In each case, the network magnitude used for residual calculation was calculated using the respective dataset.

4 Conclusion and Future Work

We have compared M_L estimates made with the Antelope real-time earthquake monitoring system used by GA during the period November 2010 to March 2018, with retrospectively processed waveform data using the SeisComP system currently used by GA. For both single-station and network M_Ls, the differences between estimates made using Antelope and SeisComP have a spread of about 0.1 magnitude unit, but there is also an apparent systematic bias of SeisComP M_Ls to values higher than those of Antelope by about 0.1 magnitude units. For the eastern and southern Australia regions, this apparent bias can be removed by pre-processing of the waveforms used by SeisComP with a high-pass filter having a corner of 2.0 or 4.0 s. For the western Australia region, such pre-filtering greatly reduces the apparent bias, but it is still significant and also has a wider distribution of Antelope-SeisComP differences than do the other regions. Because pre-filtering should reduce long-period noise that may bias the Wood-Anderson amplitude measured for the weak signals generated by small earthquakes at typically large (>200 km) distances, it is tempting to conclude that such pre-filtering results in more robust M_L estimates. However, we believe more work needs to be done to establish this as a guideline for improved magnitude estimates. Such guidelines should also consider signal-noise thresholds that are appropriate for reliable magnitude estimation, noting that stricter requirements will result in fewer stations being used to estimate a network magnitude.

Further work should include investigation of some of the large outliers in the differences between Antelope and SeisComP M_Ls, in particular for the western Australia region. We will also consider tests using synthetic seismograms and realistic estimates of noise to establish that pre-filtering really produces more robust M_L estimates. Finally, we should also re-examine both the attenuation terms used in the regional M_L formulae and the regionalisation itself, since the quantity and quality of waveform data has vastly improved over what was available in the late 20th century when the current set of magnitude scales was developed.

5 Acknowledgements

This authors publish with the authorisation of the CEO of Geoscience Australia.

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