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Towards a homogeneous earthquake catalogue for Australia

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Abstract

An earthquake catalogue based on the moment magnitude scale is required for calculation of seismic hazard in Australia. However, the estimation of moment magnitudes for small to moderate sized earthquakes is not a routine process at seismic observatories, resulting in a catalogue mainly based on the local magnitude scale for Australia. In this study we explore the application of an automated procedure to estimate moment magnitudes by minimizing the misfit between observed and synthetic displacement spectra. We compile a reference catalogue of 15 earthquakes with moment magnitude values between 3.8 and 5.4 which were based on previous studies. The moment magnitudes were then recalculated and we find that the estimated moment magnitudes are in good agreement with reference values with differences mainly lower than 0.2. However, the reported local magnitudes of the selected events are consistently higher than the reference values with differences between 0.3 and 1.0. The automated procedure will be applied to compute moment magnitudes of the well recorded events in Australia, and to derive a scaling relation between local magnitude and moment magnitude.

Keywords: Seismic hazard assessment, Earthquake catalogue, Moment magnitude

Introduction

A homogeneous earthquake catalogue based on moment magnitude (Mw) plays a key role in estimating seismic hazard for a region of interest. Such a catalogue is required for estimating earthquake recurrence parameters, and also the magnitude measure, i.e. Mw, is consistent with those used by ground motion prediction equations (GMPEs). However, the seismic source signal from small-to-moderate sized earthquakes is often masked by the background seismic noise making Mw difficult to resolve. Consequently, this often results in a catalogue with magnitude measures other than Mw. As a result, in seismic hazard assessment (SHA) studies, it is a common practice to use empirical relationships to convert earthquake magnitudes reported in different scales to Mw. It has been shown that the results of SHA are sensitive to the selection of the magnitude conversion equation (Rong et al. 2011; Leonard et al. 2014), and consequently care should be taken in developing such equations for the region of interest. In this regard computation of Mw for small-to-moderate sized earthquakes becomes vital to develop a robust magnitude conversion equation (Edwards et al. 2010).

In Australia, the earthquake catalogue is mainly based on local magnitude (ML), and the 2013 National Seismic Hazard Map (NSHM) is developed assuming that, for small to moderate earthquakes (ML<6.0), there is no significant difference between ML and Mw (Leonard et al. 2014). Indeed this may not be the case as shown by Allen et al. (2011) for Australia, and also by similar studies for regions of low-to-moderate seismicity (Edwards et al. 2010). However, Leonard et al. (2014) noted that using such conversion equations leads to unrealistically high b-values in Australia.

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Currently Geoscience Australia (GA) is revising the NSHM for input to the review of the earthquake local standard. For this revision, we are aiming to compile a homogeneous earthquake catalogue based on Mw for Australia by 1) recalculating ML, and also computing Mw based on waveform data for as many earthquakes as possible, and 2) deriving empirical relationships for magnitude conversion. In this paper, we present the results of verifying a procedure to estimate Mw by minimizing the misfit between observed and synthetic displacement spectra. First we introduce the methodology and the reference catalogue which includes earthquakes with original Mw magnitudes derived from other studies. Then we present the Mw estimates from this study and compare them with those from the reference catalogue. Finally, we discuss the results and outline areas for future study.

Methodology

In this study KIWI tools, an open source seismological software for seismic source inversion, is used (Heimann 2011; Cesca et al. 2010). For a given earthquake location and initial magnitude estimation, we retrieved point source parameters, i.e. seismic moment (M0), strike, dip, rake, and depth by minimizing the L2-norm misfit function between the observed and synthetic displacement spectra. Performing the calculations in the frequency domain makes the results less sensitive to the problem of correct trace alignment; however, since the polarity information is missing, it prevents distinction between pressure and tension quadrants. For a given point source and recording station, at each inversion iteration, the synthetic seismograms (three-component) were generated using a pre-calculated Green's function. In this study, the pre-calculated Green's functions are generated based on the IASP91 global velocity model (Kennett and Engdahl 1991). This model is also in use by GA to locate earthquakes in Australia as part of the earthquake monitoring and alerting function. In addition, to assess the robustness of the results we repeated the analysis using earthquake locations reported by other agencies, and also Green's functions calculated based on the CRUST2.0 velocity model (Bassin et al. 2000).

Data

To verify the Mw computational approach, we compiled a reference catalogue of 15 earthquakes with original moment magnitude values between 3.8 and 5.4 which were based on previous studies (Table 1). It should be noted that we only selected earthquakes with available broadband seismic data at local and regional distances, i.e. hypocentral distance<1000 km. The original Mw values and focal mechanism parameters were determined in the time domain by inverting broadband seismic data using 1D theoretical Green's functions. For each event, the velocity model used in previous studies for generating synthetic seismograms is also listed in Table 1.
Figure 1 shows the geographical distribution of the selected events and recording stations. It is interesting to note that although there are only a few earthquakes in this list, they represent the earthquakes in Australia relatively well in terms of location and recording stations. For the selected events, we retrieved seismic waveforms and instrument response information from IRIS. The waveforms were pre-processed by adjusting the baseline shifts, and correcting for instrument response and then integrating these to obtain displacement time-series. For inversion the frequency band of 0.03-0.1 Hz is used for records of earthquakes with ML>4.0. To exclude noisy traces from the process, we then analysed the signal-to-noise ratio (SNR) by testing three criteria: (1) the ratio of the whole record maximum velocity to the pre-event maximum velocity is greater than 12; (2) the ratio of the whole record's maximum displacement to the pre-event maximum displacement is greater than 8; (3) In the frequency range of interest, the ratio of the signal spectrum to the noise spectrum is at -

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Table 1: List of the earthquakes studied in this paper.

ID	Date	Time	Latitude	Longitude	Depth	ML	Mw (ref)	Reference	Crust model	Mw (this study)	Misfit	GOF[4]
eve_1	2015-10-13	6:54:58	-22.582	120.897	11.3	4.4	4.10	De[1]	CUB	4.0	0.246	A
eve_2	2015-02-15	15:57:10	-25.219	151.374	15.0	5.2	4.80	De	CUB	4.8	0.416	B
eve_3	2014-10-31	19:15:25	-30.815	121.232	10.0	4.2	3.90	Sip[2]	AusREM-MOD	3.8	0.339	A
eve_4	2014-04-29	9:54:56	-32.796	139.541	13.0	4.7	4.10	De	CUB	4.1	0.782	D
eve_5	2014-02-26	0:00:07	-30.679	121.187	00.0	4.6	4.34	Her[3]	CUS	4.2	0.319	A
eve_6	2013-06-09	14:22:13	-25.967	131.975	01.1	5.7	5.43	Her	CUS	5.3	0.382	A
eve_7	2012-06-19	10:53:29	-38.304	146.200	10.0	5.4	4.93	Her	CUS	4.8	0.313	A
eve_8	2012-06-08	11:31:00	-30.759	150.413	00.0	4.2	4.03	Her	CUS	4.0	0.544	C
eve_9	2012-03-23	9:25:18	-26.151	132.181	13.2	5.7	5.30	Her	CUS	5.1	0.376	A
eve_10	2011-04-16	5:31:19	-20.005	147.676	10.0	5.3	5.04	Her	CUS	5.0	0.291	A
eve_11	2010-04-20	0:17:10	-30.745	121.769	10.0	5.0	4.00	Sip	AusREM-MOD	4.1	0.498	B
eve_12	2009-03-18	5:28:21	-38.294	145.789	14.9	4.6	4.42	Her	CUS	4.3	0.383	A
eve_13	2009-03-06	9:55:39	-38.353	145.617	12.0	4.6	4.45	Her	CUS	4.4	0.394	A
eve_14	2009-03-05	12:53:51	-30.240	118.037	05.0	4.5	4.05	Her	CUS	4.0	0.356	A
eve_15	2009-01-31	8:47:03	-30.238	117.815	03.1	4.6	3.78	Her	CUS	3.8	0.348	A

[1] original Mw values are from De Kool (personal communication)
[2] original Mw values are from Sippl et al. (2015)
[3] original Mw values are from Herrmann available at: http://www.eas.slu.edu/eqc/eqc_mt/MECH.AU/
[4] goodness-of-fit class

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- least 2.5. Figure 2 shows an example of seismograms generated from the 31 January 2009 ML4.6 earthquake in Western Australia (ID: eve_15, Table 1). The records are colour coded based on the above SNR tests. For the inversion, we excluded the records which do not meet any of the above SNR tests.

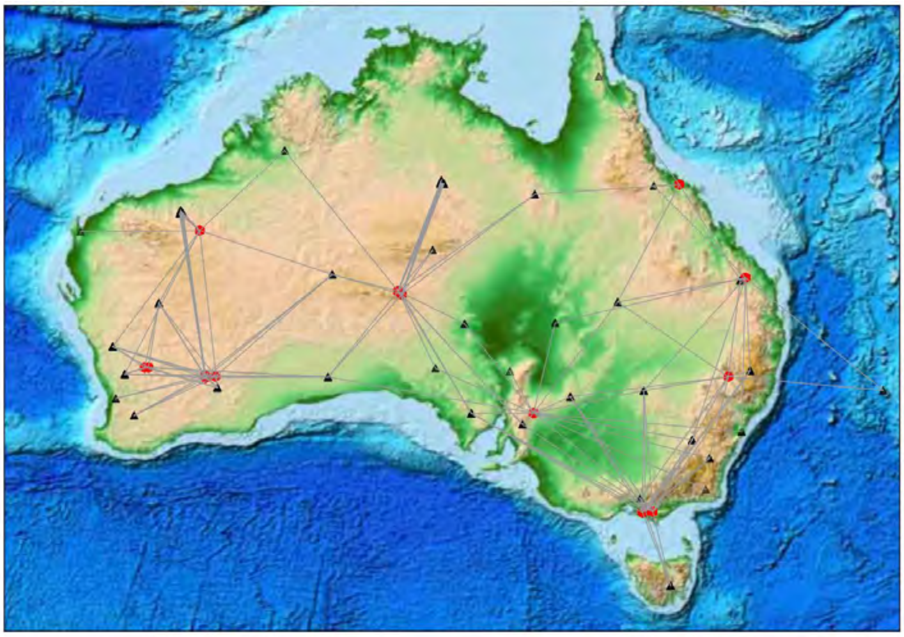

Figure 1: Spatial distribution of the selected events (red circles) and recording stations (black triangles). Note that, based on SNR criteria, not all of the stations are used in the analysis.

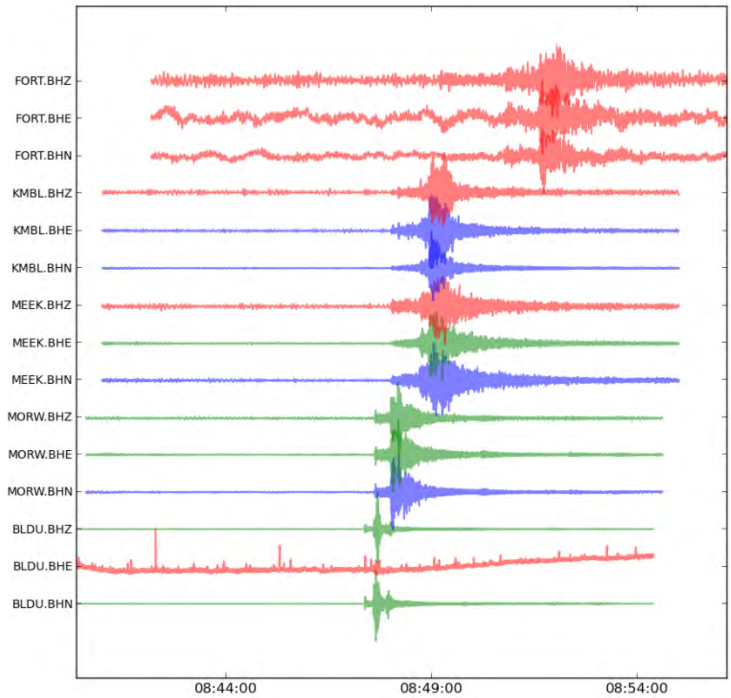

Figure 2: Seismograms generated from the 31 January 2009 ML4.6 earthquake in Western Australia. Seismograms that pass all of the SNR tests are shown in green, those that pass the first two tests are shown in blue, and those which fail all of the tests are shown in red.

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Results

We computed the Mw values of earthquakes listed in Table 1 using the waveform inversion technique. Figure 3 shows an example of the inversion results for the 19 June 2012, ML5.4 earthquake in Victoria (ID: eve_7, Table 1). The results show a good agreement between the synthetic and observed spectra in the frequency range of interest with reasonably small overall misfit value. Considering the relative misfit curve of the source depth parameter, the results indicate an earthquake with a well constrained depth value at 13 km. The focal mechanism parameters are also retrieved; however, since the inversion is carried out in the frequency domain, ambiguity for pressure and tension quadrants exists.

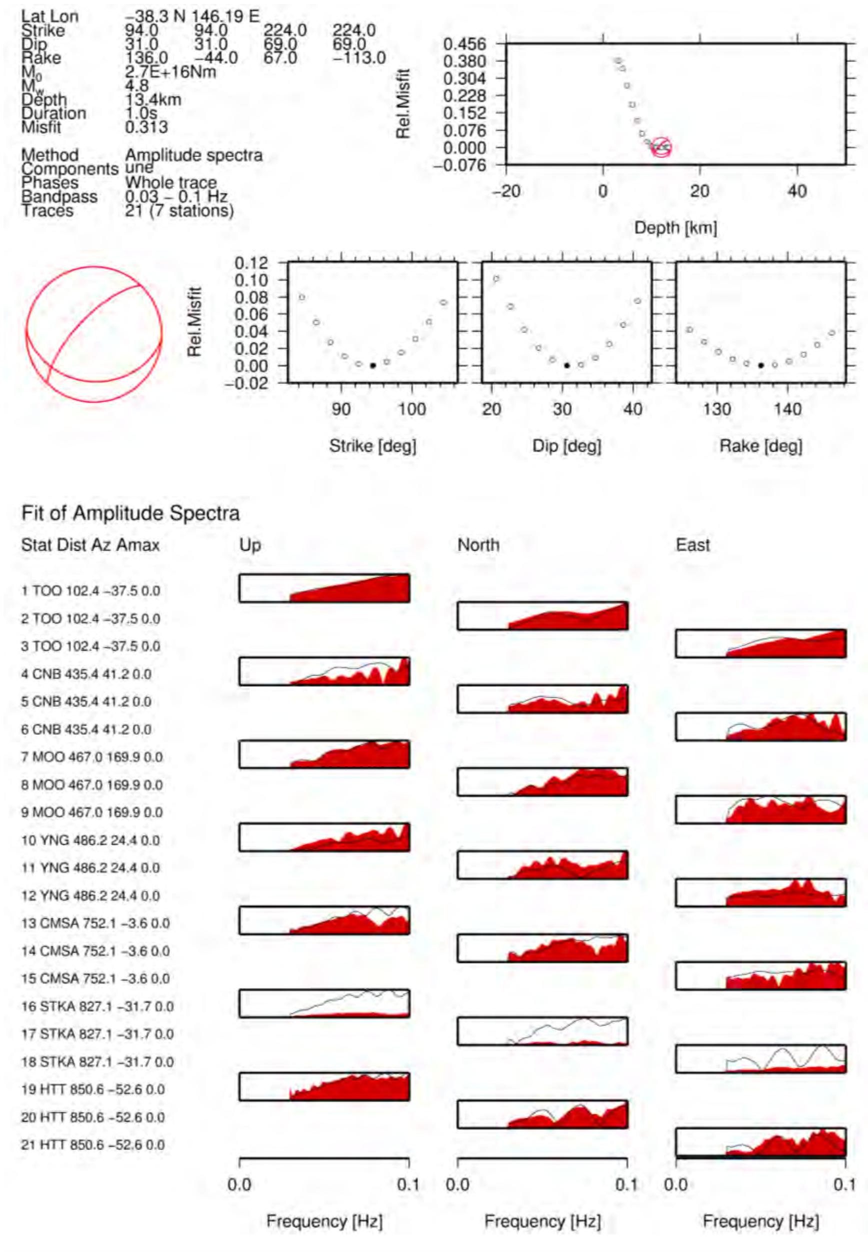

Figure 3: Inversion results for the 19 June 2012, ML5.4 earthquake in Victoria.

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Figure 4 compares Mw values from the reference catalogue with those determined in this study. Comparison with ML values reported by GA is also presented. For each event the difference between original Mw value and the value from this study is calculated. It can be seen that for most of the events (nine out of 15 events) the difference is less than 0.1, for five events it is between 0.1 and 0.2, and there is only one event with difference value between 0.2 and 0.3. On the other hand for ML values, most of the calculated errors are larger than 0.3. Notably there is one earthquake, i.e. 4 April 2010, ML5.0 earthquake in Western Australia (ID: eve_11, Table 1), with a difference of 1.0. It is also interesting to note that the reported ML values are consistently larger than the reference Mw values. To a degree, this may imply the need for recalibration of region specific correction terms used in the calculation of ML for earthquakes in Australia.

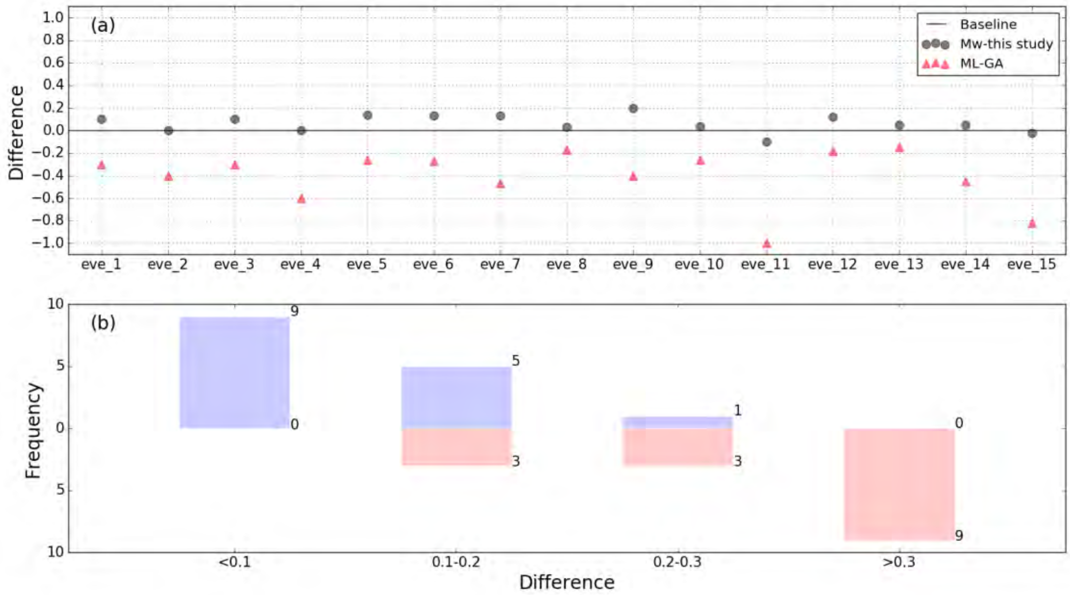

Figure 4: (a) The difference between original Mw and Mw computed in this study (black circles), as well as original Mw and ML reported by GA (red triangles). (b) Frequency of the differences between original Mw and Mw computed in this study (blue bars), as well as original Mw and ML reported by GA (red bars)

For each event, we defined a goodness-of-fit class based on the calculated misfit value. Earthquakes with overall misfit value of <0.4, <0.5, <0.6, and >0.6 are classified as A, B, C, and D, respectively. For the selected events, there are only two events classified as C and D and the rest of the events are in either class A or B (Table 1). We would expect that overall misfit value to be reduced by using more accurate velocity models; however, as shown by previous studies, we do not expect that this would change the computed Mw values significantly (Delouis et al. 2009; Sippl et al., 2015). In fact, for the selected events, we are computing very similar Mw values to those from previous studies that use different velocity models than the one used in this study. To further verify this, we repeated the analysis using Green's functions calculated based on the CRUST2.0 velocity model, and also earthquake locations reported by other agencies. For all of the selected events, the computed Mw values are within +/-0.2 of the initial estimates of Mw. However, it should be noted that the focal mechanism parameters and also depth parameter can be sensitive to the input velocity model, and using more accurate velocity models would enhance the results significantly (Domingues et al. 2013).

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Conclusions

In this study we analysed local and regional broadband seismic data of 15 earthquakes to compute Mw using a waveform inversion technique. All of the selected earthquakes are shallow-crustal earthquakes in the Australian stable continent, and have original moment magnitude values in the range Mw 3.8-5.4. In spite of using a different velocity model and inversion tool, the computed Mw values show very good agreement with those from previous studies. On the other hand we noted that ML values reported by GA are consistently larger than the reference Mw values, suggesting the need for developing a robust ML-Mw conversion equation for Australia. The future work includes: 1) recalculating ML, and also computing Mw based on waveform data for as many earthquakes as possible, and 2) deriving empirical relationships for magnitude conversion. We will also study the correlation of Mw with other magnitude scales such as body-wave magnitude (mb).

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