A Spatially Distributed Earthquake Source Model of Australia

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Abstract

A spatially distributed earthquake source model was derived from the spatial smoothing of historical seismicity using the earthquake catalogue described by Leonard (2007). This approach is similar to that of Cuthbertson (2006) and to the main approach used to describe the seismic potential of the eastern United States in the U.S. National Probabilistic Seismic Hazard Maps (Frankel et al., 2007). It is intended that this model complement other models, such as Brown and Gibson (2004) and Ninis and Gibson (2006), which use geological criteria to identify zones of uniform seismic potential, and Clark (2006), which uses neotectonic data. The spatial smoothing approach has the advantages of simplicity and of avoiding uncertainty in the geological definitions of zones, but has the disadvantage of not making use of potentially informative geological data. The spatially distributed earthquake source model is in the form of a-values and b-values on a 10 km x 10 km grid throughout Australia.

Keywords: Seismicity, seismic hazards

1. INTRODUCTION

A spatially distributed earthquake source model was derived from the spatial smoothing of historical seismicity using the earthquake catalogue described by Leonard (2007), illustrated in Figure 1. It contains four regions which have relatively high levels of seismic activity and catalogue completeness compared with the rest of Australia. These four regions are:

- Southeastern Australia - SEA
- Southwestern Australia – SWA
- South Australia – SA
- Northwestern Australia – NWA

The remaining area is referred to as the Rest of Australia (RA).

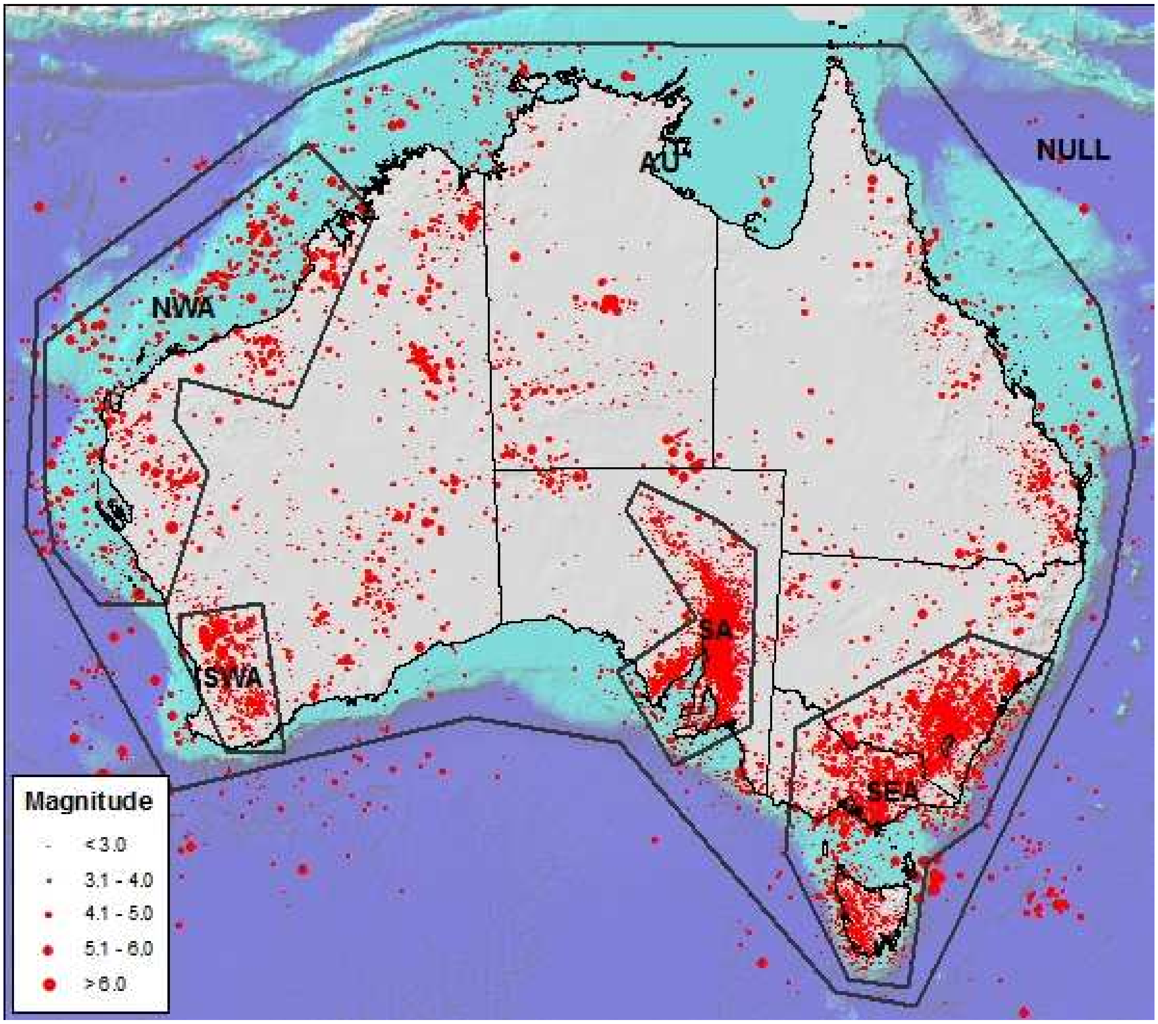

Figure 1: Earthquake catalogue and seismic source regions. Source: Leonard (2007).

The catalogue completeness, listed in Table 1, is taken from Leonard (2007) except that for SWA, we assumed completeness beginning in 1940, not 1880. There are no events in the SWA catalogue before 1940. Although it is thought that events larger than magnitude 5 should have been detected in this region since about the turn of the century, we have conservatively chosen a completeness interval starting in 1940.

Table 1. Completeness of the Australian Earthquake Catalogue

	>3	>3.5	>4	>4.5	>5	>5.5	>6
SEA	1960		1955		1880		1880
SA	1970			1880	1880		1880
SWA	1960			1940	1940		1940
NWA	1980		1965			1910	1910
RA	1970				1960		1910

2. METHOD

The a-values of the 10 x 10 km grid cells for each region were derived from the smoothed spatial distribution of seismicity, using the b-value for that region and the number of earthquakes greater than or equal to a certain magnitude within each grid cell. We used three lower magnitude cutoff values: M3, M4 and M5, and averaged the results. We calculated separate a-value grids for each region. For each a-value grid point we calculated the number of events ≥ M0, and summed the grids for each region to give country-wide coverage of the number events ≥ M0. Kernel density algorithms were used to calculate smoothed seismicity density for each input data set. In regions with longer completeness intervals and hence higher densities of events (SEA, SWA, SA and NWA), a correlation distance of 100 km was applied. The sparse historical seismicity in the rest of Australia required greater smoothing. In this region, a seismic density grid was created by averaging smoothed grids calculated using correlation distances of 100, 200 and 300km.

The Gutenberg-Richter cumulative magnitude – frequency relation is given by:

$\mathrm{Log}_{10}N = a - bM$

where N is the number of earthquakes with magnitude equal to or larger than M. The spatially distributed earthquake source model developed in this study is provided in the form of a-values (for 100 years) and b-values on a 10 km x 10 km grid throughout Australia. The map projection used is GDA 1994, zone 53. The grid has 420 rows and 510 columns. We assume that the maximum earthquake magnitude of the distributed earthquake source is magnitude 7.5 throughout Australia.

The procedure used to generate these grids of a-values and b-values is as follows.

1. Generate b-values using least squares regression for each of the following regions:
   a. Southeastern Australia - SEA
   b. Southwestern Australia – SWA
   c. South Australia - SA
   d. Northwestern Australia - NWA
   e. The Rest of Australia – Rest of AU
2. For each region calculate separate a-value grids, using the b-values determined from step 1 and appropriate completeness intervals.
3. Calculate for each a-value grid the number of events ≥ M0 (the total number of earthquakes of any magnitude) per grid cell.
4. Sum grids for each region to give a country-wide coverage of the number events ≥ M0.
5. Generate a national a-value grid

3. CALCULATION OF REGIONAL b-VALUES

The b-values, listed in Table 2, were derived using the maximum likelihood method (Weichert, 1980), in all regions except SWA and NWA. In those two regions, we used least-squares regression, because there are inflections in recurrence curves for these regions and the maximum likelihood method is unduly sensitive to such inflections. The recurrence relations for SEA obtained using maximum likelihood and least squares are compared in Figure 2. The maximum likelihood estimate has a lower b-value than the least-squares estimate, and lies well above the historical data for magnitudes larger than 5.75. The discrepancy between the historical catalogue and the prediction of our model is largest for SEA, as shown in Table 3. The maximum likelihood estimates were made assuming a maximum magnitude of 7.5 throughout Australia.

Table 2. Parameters (including b values) used for each regional a-value calculation

Region	Method used *	b-value	Correlation distance (km)	Minimum Magnitudes
SEA	ML	0.82	100	M3, 4, 5
SWA	LS	0.70	100	M3, 4.5, 5
SA	ML	0.84	100	M3, 4.5, 5
NWA	LS	0.86	100	M3, 4, 5.5
Rest of AU	ML	0.82	Equally weighted average of 100, 200, 300	M3.5, 4, 5.5

* ML: maximum likelihood; LS: least squares

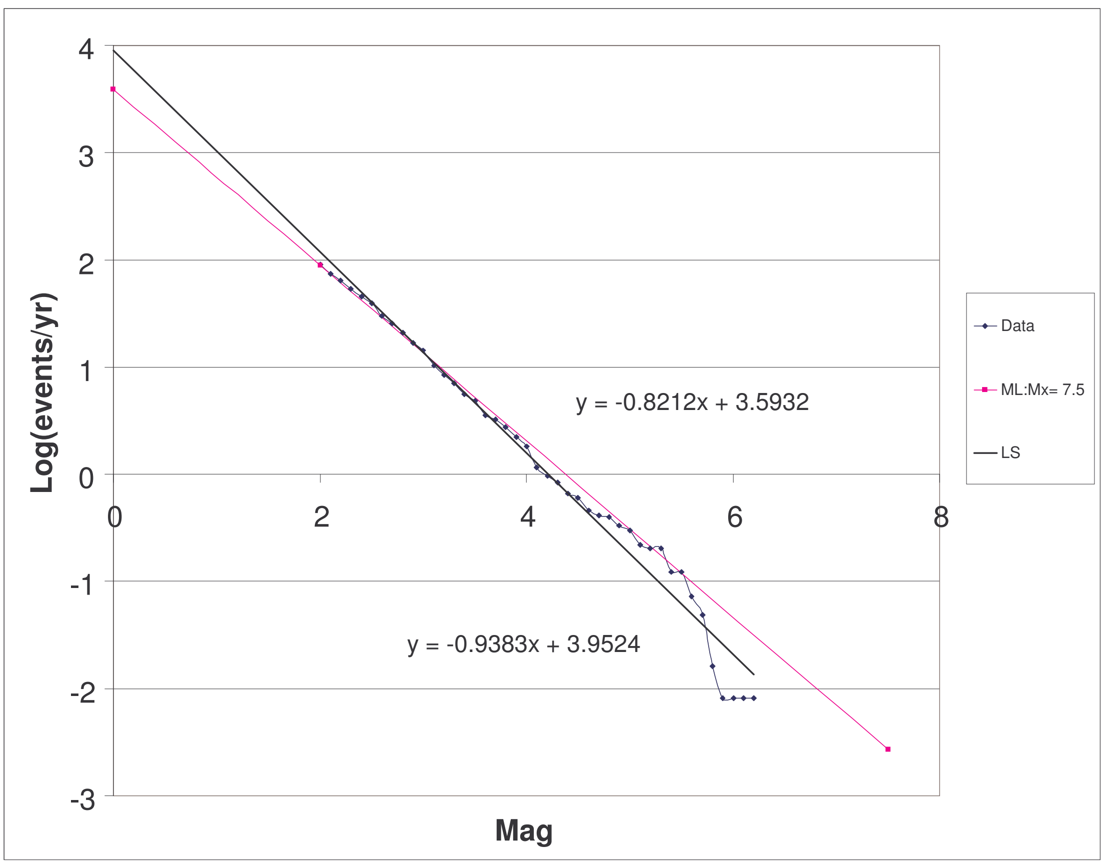

Figure 2 Recurrence data and recurrence relations for SEA using least squares (LS; black line) and maximum likelihood (ML; purple line).

4. CALCULATION OF a-VALUE GRIDS

The a-values for each 10 x 10 km grid cell were derived from the smoothed spatial distribution of historic seismicity, using the b-values and the number of earthquakes greater or equal to a certain magnitude within each grid cell. Unless the cumulative magnitude – frequency relation shows no deviation from a straight line, the a-value calculated will depend on the minimum magnitude used. The calculation is therefore repeated using three different magnitude ranges, so an average may be calculated.

The steps involved in calculating a-value grids for each region and for each minimum magnitude are as follows:

i) Input spatial databases are created for each region containing all events greater or equal to a defined minimum magnitude within the completeness interval from Leonard (2007). For each of the four regions, three input databases are used, with minimum magnitudes of M3, M4 and M5. For the rest of AU, the catalogue is not complete down to magnitudes of M3, so minimum magnitudes of M3.5, M4 and M5 are applied

ii) Kernel density algorithms calculate smoothed seismicity density (per km^2) for each input database. In regions with longer completeness intervals and hence higher densities of events (SEA, SWA, SA and NWA) a correlation distance of 100 km is applied. The rest of the country requires greater smoothing due to the sparse data distribution. In this region, a seismic density grid is created by averaging smoothed grids calculated using correlation distances of 100, 200 and 300km. Smoothing uses a quadratic kernel function.

iii) Within a region, kernel density maps for each minimum magnitude are averaged and divided by the completeness interval, to give event rates of Mx and greater. Numbers are adjusted to give rate per 100 years, per 100 km^2 grid cell.

iv) The number of events ≥ Mx and the b-values are used to calculate the a-value for each grid cell.

v) a-values are then converted to a grid of the number of events of M0 and greater.

The parameters used in this process are given in Table 2. These include the regional b-value, the correlation distance used in spatial smoothing, the magnitudes that were separately smoothed and combined, and the completeness intervals.

To create the final a-value grid for each region, the a-values calculated from the different magnitude ranges are averaged as follows:

i) Input grids calculated for different minimum magnitudes give the number of events of M0 and greater (over 100 years, in each grid cell - an area of $100km^2$).

ii) Where cells have no data, cells are populated with a rate of 0.

iii) Event rate grids are averaged using equal weights

iv) An a-value is calculated from the averaged event rate grid.

We averaged the grids of event frequency ≥ M0 (i.e. 10^a), rather than a-value. Averaging a-values gives a closer answer to least squares regression, but does not deal with regions of no seismicity. Averaging event rates gives a slightly less accurate result but accounts for areas of no historical activity.

The event frequency grids for each region are summed to produce a country-wide coverage of the number events ≥ M0. This is converted to a-value using the national b-value grid.

5. DISCUSSION

The gridded "a" values are shown at the top of Figure 3, and the predicted number of earthquakes of magnitude equal to or larger than 5 predicted by our model is shown at the bottom of Figure 3. There is fairly good agreement between the "a" values and "b" values of our model and that of Leonard (2007), but the latter model has a lower b-value in Southwestern Australia than our model (0.58 compared with 0.70). The distributed earthquake source model is compared with the historical earthquake catalogue of Leonard (2007) in Table 3. This table compares predicted rates of earthquakes in different magnitude ranges with historical values in each of the regions. The agreement overall is good for magnitudes up to 5, but there is a tendency for our model to overpredict the numbers of recorded earthquakes having magnitudes of 6.0 and larger.

Table 3: Comparison of source model and earthquake catalogue event rates

	SEA				SWA				SA			
	≥M3	≥M4	≥M5	≥M6	≥M3	≥M4.5	≥M5	≥M6	≥M3	≥M4.5	≥M5	≥M6
Catalogue Event Rate per 100 yr	1393	180	30	0.8	334	32	20	3.1	662	28	10	0.8
Model Event Rate per 100 yr	1264	191	29	4.3	390	35	15	3.0	557	31	12	1.6
% Diff	-9%	6%	-3%	387%	13%	3%	-25%	3%	-15%	10%	20%	100%

	NWA				Rest of AU			All AU		
	≥M3	≥M4	≥M5.5	≥M6	≥M4	≥M5	≥M5.5	≥M4	≥M5	≥M6
Catalogue Event Rate per 100 yr	1554	354	12	3.2	574	77	19	1313	219	11
Model Event Rate per 100 yr	1774	243	12	4.6	597	90	35	1189	179	27
% Diff	14%	-31%	0%	43%	4%	29%	100%	-9%	-18%	147%

The spatially distributed a-value grid for southeastern Queensland and northeastern New South Wales is overlain on the source zones of the AUS5 model (Brown and Gibson, 2004), as updated by them in 2007, in Figure 4. The AUS5 model is based primarily on regional geology and geophysics rather than seismicity, and assumes that the clusters within zones can be replicated anywhere within the zone, but over a time period much longer than the duration of the catalogue. In general, the boundaries of the AUS5 source zones are correlated with changes in the spatially smoothed a-values. The spatial smoothing may smear out sharp boundaries that may exist due to the presence of faults or other structures.

6. CONCLUSIONS

A spatially distributed earthquake source model was derived from the spatial smoothing of historical seismicity using the earthquake catalogue described by Leonard (2007). It is intended that this model complement other models, such as Brown and Gibson (2004) and Ninis and Gibson (2006), which use geological criteria to identify zones of uniform seismic potential, and Clark (2006), which uses neotectonic data.

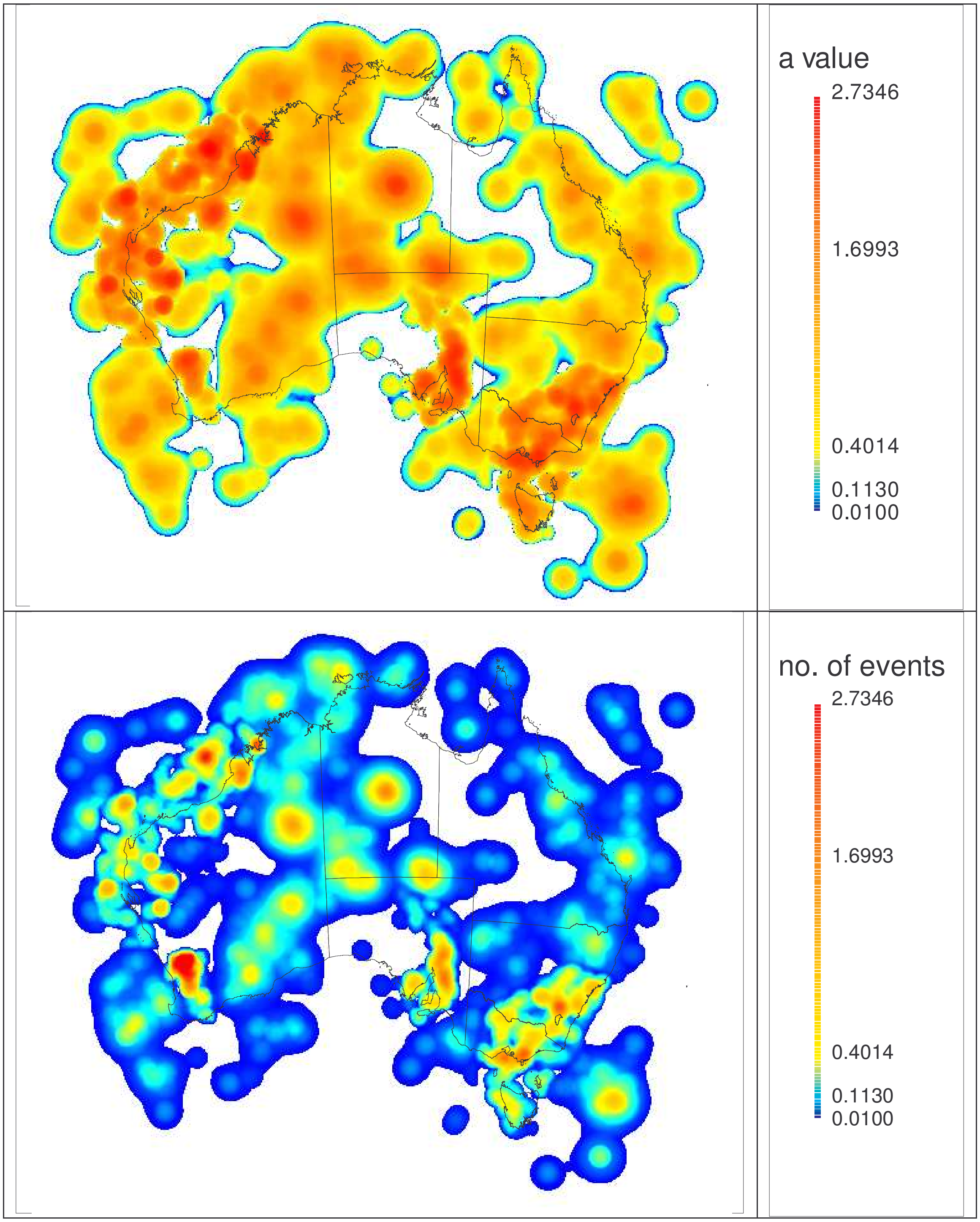

Figure 3. Top: Grid of “a” values, normalised to 100 years and 100 square km. Bottom: Grid of number of events of M>5 per 500 years per 10,000 square km.

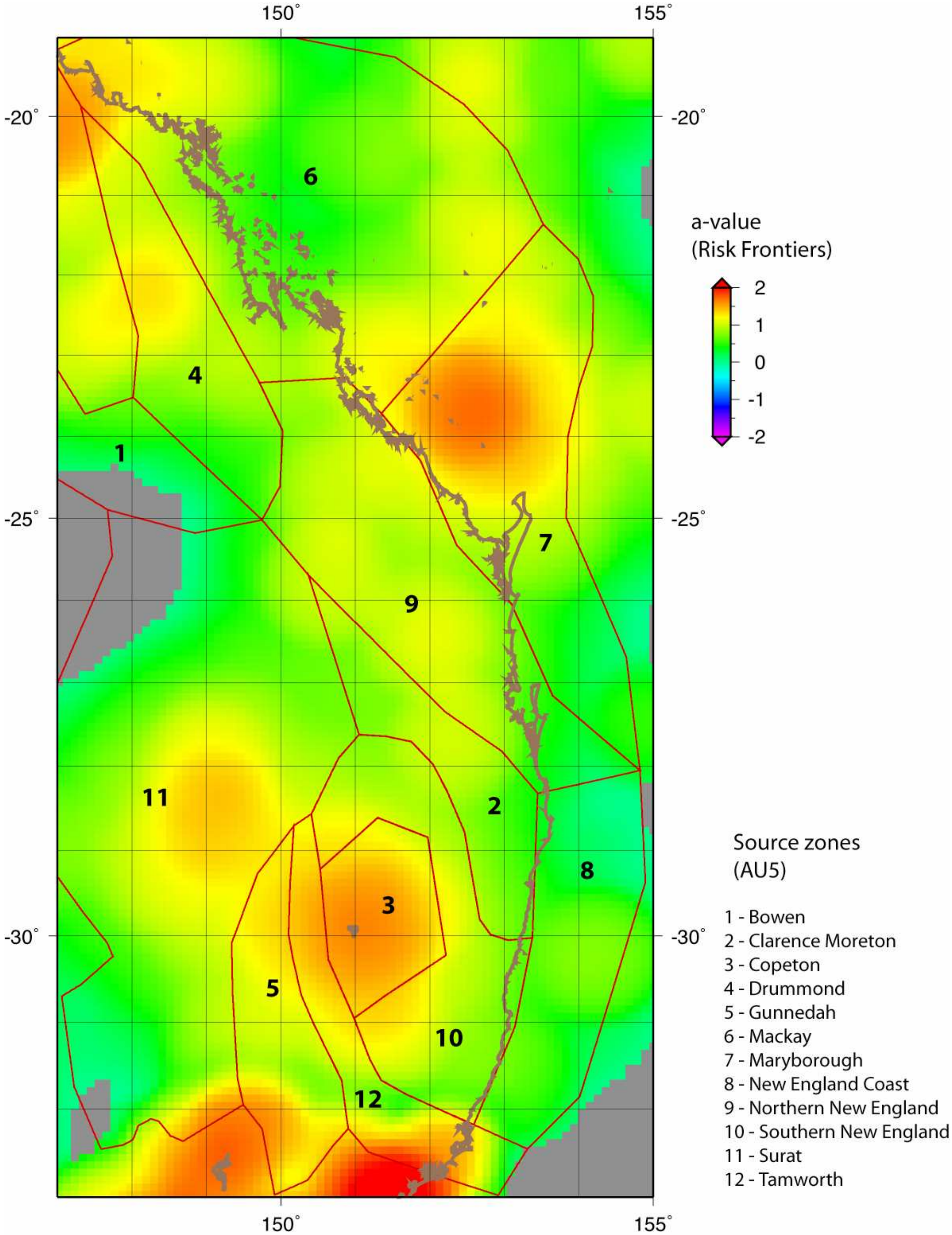

Figure 4. Overlay of the a-value grid from this study on the source zones from the AUS5 model (Brown and Gibson, 2004) shown as red polygons.

In the approaches developed by Brown and Gibson (2004) and Ninis and Gibson (2006), some of the seismicity was associated with specific faults, but this has not yet been done in the present model. The spatial smoothing approach has the advantages of simplicity and of avoiding uncertainty in the geological definitions of zones, but has the disadvantage of not making use of potentially informative geological data.

7. ACKNOWLEDGMENTS

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