Towards Automatic Generation of Isoseismal Maps - a Preliminary Schema using Recent Geoscience Australia Data

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Abstract

On-line felt earthquake reporting has been available in Australia for nearly a decade now. However, processing of these data have all been done manually so far, if at all. A procedure has been developed to automatically process emails received in response to felt earthquakes. With minimal user intervention, Modified Mercalli Intensities (MMI's) and locations are assigned, and a map prepared. The map also shows the average isoseismal contours of MMI III to V based on some new isoseismal radii formulae. Using this procedure, new maps have been prepared for eight recent or relatively recent Australian felt earthquakes.

1.0 INTRODUCTION

Isoseismal maps were compiled regularly in the early days of seismology, although the practice has become less popular in recent years. The Bureau of Mineral Resources has published three volumes of isoseismal maps (Everingham et al, 1982, Rynn et al, 1987, and McCue et al, 1995). These maps were generally prepared after questionnaires were posted out to affected areas, or research done into historical newspaper records. However, these maps are time-consuming to prepare, and there are serious concerns about the degree of subjectivity involved, which in turn raises questions about their intrinsic value in any case.

The Annual Seismological Report series, published by Geoscience Australia (GA), reviews seismicity in Australia for the years 1980 to 1999, and has been used as a vehicle to publish isoseismal maps. Frequently 10 maps or so per year would be published, but since the last year to be reviewed was 1999, there are few isoseismal maps available for more recent events. Isoseismal maps were prepared for the 2003 Bowral NSW event (GA) and the 2006 Caulfield, Victoria event (Seismological Research Centre, Melbourne), but were not published.

Since the advent of the internet attention has turned towards receiving this data "online". Recent analyses of felt intensity data received through the USGS "Did You Feel It" (DYFI) program have indicated that the data can be "robust and of surprisingly high utility" (Atkinson & Wald, 2007). ".. They appear to offer the potential to not only describe ground-motion effects qualitatively, but to be used in quantitative scientific studies". This of course is in a country where the internet may generate over 15,000 responses to a large earthquake, but that does not mean that the possibilities should be ignored in a smaller country like Australia.

Strictly speaking, isoseismal maps contain contour lines, but sometimes they are just the plotting of individual intensity values at locations where the event was reported felt - ie, without the addition of interpreted isoseismal contours, which can be highly subjective in any case. This study does not extend to the drawing interpretation of contour lines based on reported intensity data.

2.0 FELT REPORT FORMS IN CURRENT USE

2.1 Geoscience Australia

TABLE 1 The Geoscience Australia form & MMI values assigned

GA Questions	**Response choices**						
Felt by? **MMI assigned**	Very few	several 2	Many 2	All in home 3	All in community 4		
Awakened? **MMI assigned**	None	Few 2	many 3	All in home 4	All in community 4	Other	
Frightened **MMI assigned**	None	Few 3	Many 3	All in home 4	All in community 4	General panic 6	Other
Hanging objects **MMI assigned**	None	moderately 4	violently 6				
Earth noises	Faint	Moderate	Loud	Other			
Monuments, water tanks		cracked	Twisted	Overturned			
Trees, bushes, cars shaken			Free text comment		Yes to any = MMI 6		
Small objects shifted overturned etc			Free text comment		Yes to any = MMI 5		
Ground cracks, landslides etc			Free text comment		Yes to any = MMI 7		
Rattling of doors, windows, dishes			Free text comment		Yes to any = MMI 3		
Creaking of building			Free text comment				

Geoscience Australia (GA) has had an on-line felt report form available on line its website for approximately seven years, which has resulted in the accumulation of a significant amount of data. This form retains many of the questions used in the postal questionnaire, and allows much free-format entry, in contrast to the emphasis on check-box returns as seen in the DYFI form. The GA form is summarised in Table 1.

2.2 The United States Geological Survey (USGS)

It is interesting to compare this form with the USGS "Did You Feel it" on-line form, summarised below in Table 2. This form asks more questions directly related to felt effects, and fewer about ground conditions (rocky, sloping etc) or type of building construction. Also, the USGS form restricts users to check-box style answers, with no scope for verbose descriptions from the users.

Table 2. The "Did You Feel It?" Schema

DYFI questions	**Response choices**					
Describe ground shaking	Not felt	weak	mild	Moderate	strong	Violent
Motion index	0	1	2	3	4	5
Describe your reaction **Reaction index**	No reaction 0	Very little reaction 1	excitement 2	Somewhat frightened 3	Very frightened 4	Extremely frightened 5
Did others near by feel the earthquake **Felt Index**		No answer 0.72	No others felt it 0.36	Only some felt it 0.72	Most felt it 1.00	almost everyone felt it 1.00
Did objects topple / fall off shelves **Shelf index**		No 0	A few toppled/fell 1	Many fell off 2	near every thing fell 3	
Pictures moved/knocked askew ?		No	Yes, but not fall		Yes & some fell	
Picture index		0	1		2	
Did furniture or appliances slide,tip		No	Yes			
Furniture index		0	1			
Was it difficult to stand or walk ?		No	Yes			
Stand index		0	1			

Indices are assigned based on the user's responses, and a formula is used to compute a Community weighted sum, as shown below.

<u>Community weighted sum</u> = 5 felt index (0-1) + motion index (0-5) + reaction Index (0-5)+ 2*stand index (0-1) + 5* shelf index (0-3) + 2* picture index (0-1) + 3* furniture Index (0-1) + 5* damage index (0-3)*

Felt intensity maps for North American and some overseas events appear on the USGS website very shortly after their occurrence. This procedure has also been adapted for use in New Zealand by the GNS.

The "DYFI" form is an extension of the form developed by Dengler & Dewey (1988), which moved in the direction of a smaller group of questions with set replies. The responses were used to give values to a number of indices (motion, reaction, stand, shelf, picture, furniture and damage indices) which were then combined to create a Community Decimal Intensity scale (CDI), rather than specific values on the Modified Mercalli Intensity scale.

It is important to get users responses into map format and on-line fairly quickly, as this encourages the public to use the service, and helps generate more community interest in seismology.

2.3 The University of Western Australia.

A third on-line form is the one used by the University of Western Australia (UWA) and it has recently been re-modelled to make it more similar to the USGS form. It also asks more specific questions to allow a user to be more accurately located in space than is possible in either of the forms mentioned above. This form is summarised in Table 3.

Table 3 The University of Western Australia form

Questions	Response choices					
Your reaction to earthquake MMI assigned	No reaction 0	Very little reaction 2	Excited 3	Somewhat frightened 3	Very frightened 4	Extremely frightened 5
Ground motion ? MMI assigned	Not felt 0	Weak 2	mild 3	Moderate 4	strong 6	violent 7
Objects rattle /fall ? MMI assigned	Not rattle 0	Rattled slightly 2	strongly 3	A few fell 4	Many fell 5	Nearly everything 6
Pictures displaced ? MMI assigned	No 0	Yes, slightly 3	strongly 4	some fell 5		
Felt by? MMI assigned		No one 0	A few 2	About half 3	most 4	everybody 5
Awakened? MMI assigned	Not applic 0	No one 2	A few 2	About half 3	most 4	everybody 5
Urge to run outside MMI assigned		No 2	Yes a little 3	Strong 4	We left 5	We ran outside 6
Building damage? MMI assigned	No damage	Hairline cracks 5	A few large crack 6	Many large cracks 7	Masonry fell 8	Walls tilted / collapsed 9

2.4 The Seismology Research Centre.

A fourth important source of felt-report data in Australia is the Seismology Research Centre (SRC) in Melbourne, which is now a division of Environmental Systems and Services (ES&S). However, the on-line reporting form used by the SRC relies extensively on effect descriptions, rather than multi-choice check boxes. This makes automation of the process very difficult.

In an earlier discussion of the potential of on-line reporting, Love (2000) stated “Despite interest in recent years, we have not settled on a standard questionnaire in Australia”. Seven years later this is obviously still the case. However, the pros and cons of the four on-line forms mentioned above need to be thoroughly discussed before a uniform form should be adopted.

2.5 Application to Recent Australian Felt Events

While the assignment of indices, as done with the DYFI form, is not possible with the current GA form, there is scope for at least some degree of automatic processing. There is also much accumulated felt-report data at GA, and the object of this study was to develop a procedure for the automatic processing of this data, and any future data which might be received in this format. This involved devising procedures to extract important data from the emails, assign MMI (Modified Mercalli intensity) values based on these data, then assign geographic coordinates, and finally convert the data to a format which could be readily plotted.

Some of the more significant felt events with substantial numbers of on-line returns over the last few years are listed in Table 4. Seven events were selected for processing to evaluate the procedure developed (see events indicated on Table 4). In addition, an earlier significant felt event (Eugowra, NSW, 1994) for which standard questionnaires were received, and an isoseismal map prepared (McCue & Gregson, 1996), was also selected for reprocessing using this method.

Table 4 **Some of the events generating a significant number of returns from on-line forms on the Geoscience Australia (and UWA) websites since 2003.** *(asterisk indicates events for which a new isoseismal map has been prepared).*

DATE	Mag	LOCATION	Depth	#Returns	Comments
11 Dec 2003	4.3	Bowral, NSW*	5	164	
18 Nov 2004	4.0	Mole Ck. Tas	10	21	
31 Oct 2005	3.1	Lithgow, NSW*	8	22	
03 Nov 2005	-	Northern NSW	-	69	Sonic boom
28 Jan 2006	7.6	Darwin, NT	346	56	Banda Sea
04 Mar 2006	2.7	Donnybrook, WA*	0	14	UWA data
21 Oct 2006	4.2	Cowra, NSW*	15	51	
22 Oct 2006	2.9	Caulfield, Vic*	10	80	
15 Feb 2007	5.3	Shark Bay, WA*	19	15	UWA data
08 Mar 2007	3.5	Warburton, Vic*	14	86	
28 Aug 2007	4.6	Albany, WA	18	31	UWA data
09 Oct 2007	4.8	Broome Hill, WA	0	33	Plus returns 19 ex UWA

3 METHOD OF PROCESSING ON-LINE DATA RETURNS

The procedure used can be separated into a series of five steps

1) Group the emails and save in a single file
2) Run a program to save the more relevant lines in the returns
3) Import into Excel and edit keyboard entries, re-arrange columns
4) Run a program to assign intensities and location
5) Prepare a file suitable for plotting and creating the map

A number of simple QuickBasic programs have been written to implement this procedure, and they are listed, with brief descriptions, in Table 5.

Table 5 – Quick Basic programs to process returns

Program name	Function	Remarks
Abbrev	Extract selected data from emails (after converted to text)	Output a file imported to Excel
Assign	Assign an MMI value and determine geographical coordinates	Output a file with latitude, longitude and MMI values
Mkcube	Convert file to simple file suitable for plotting with GMT	

Variations on these programs were written to cope with data acquired from UWA forms, and also archived data on standard postal questionnaires. These procedures are now discussed in more detail below.

3.1 STEP 1 Grouping the messages received

The messages are received as Microsoft Outlook files, and these can be copied in bulk to a single file in simple text format. Bugs in the on-line form mean that occasional binary data finds its way into the text files, and this requires extra hand editing in the processing of the files. The emails have also been saved as comma-separated-value files, but again, because respondents sometimes add commas to their returns, extra fields are added and complicate the processing.

3.2 STEP 2 Extracting relevant data from the reports

The GA form contains many fields which are only of indirect relevance to the assignment of felt intensities. – eg, the slope of the ground, the quality of building construction. In a correctly saved return, there are 44 lines potentially containing useful data.

The first program extracts only the significant lines from the processed returns. These are the lines that indicate the sender, their location, and the fields “felt by”, “awakened”, “frightened”, “did objects rattle”, “did hanging objects sway”, “were small objects overturned”, and “was there damage”.

3.3 STEP 3 Manual data quality control

The output file from step 2 is then imported into Excel, where substantial editing may be required, eg. where people have misspelled their nearest town, or their address or other information is entered into the wrong column. A form which relies more heavily on check boxes would make processing easier.

The data is also sorted into Town order at this stage, which is useful at a later stage of processing.

When the line being processed is a free-format line, it is abbreviated, but left long enough to indicate if it contains useful data.

3.4 STEP 4 Assessment of local MMI intensity and assignment of a location

Responses to the various questions in the check-boxes can be roughly equated to various values on the MMI scale. The relationships we have adopted are listed in Table 1. It is expected that these relationships will need revision but this can easily be accommodated by revising the computer program.

The form also asks for other responses where free text is accepted. Here certain simplifying assumptions have been made. For example, if anything is entered in “describe rattling”, the MMI will be at least 3, and if anything at all in “were small objects overturned” the intensity will be at least MMI 5. However, in any instance where the computer wishes to assign an intensity of 5 or more, the user is given the opportunity of reviewing the response before accepting the assigned value.

While the above represent major generalisations, they at least allow the rapid processing of data – which might be very valuable should GA be inundated with reports following a large event. Flagging particular returns assists later closer scrutiny. Also, since the original responses are being saved at step 3, re-evaluation of assigned values is possible, and adjusted maps can be quickly prepared.

The felt intensity at a particular location is then assumed to be the maximum indicated from the various individual questions (above) which have been examined above. This is different from the DYFI method, where the final assigned intensity value is the result of a formula applied to the various indices.

An important feature to note here is the apparent bias towards under-estimation of intensities. Higher values (eg, MMI 5) are allocated on the basis of responses like “panic” and “alarm”, and the occurrence of minor damage – if these effects are not noted, then a lower value is assigned. However, Dengeler & Dewey (1998) note that (on the basis of evaluating about 6000 reports for the 1994 Northridge earthquake) that “Even at intensities 8 and 9, relatively few people (about 15%) described their reaction as ‘panic’ and only about 12% reported major damage to their homes”.

The observer's “town” is then matched against a file containing the names and locations of towns/villages, derived from the Australian Gazetteer. This procedure is appended to the same program that assigns felt intensities. A file is generated containing index, town, latitude, longitude and MMI value.

3.5 Step 5 Plotting the data

The most convenient plotting tool is GMT (Generic Mapping Tool), and the next program uses the last output mentioned above to produce a file which can be directly input into this program.

The file only contains latitude, longitude and a value representing MMI value. A colour value must be inserted here so as to generating a “warming” sensation as the MMI value increases upwards. Also, because there may be many returns from a single town, we have added a procedure to offset values at repeated locations by a small amount (0.01 degrees). This results in the plotting of off-set cubes, which allows instant identification of localities which have generated many returns, as well as the range of values that may be found there.

The program outputs a file in a format suitable for reading into the GMT program, which is then used to produce an isoseismal map.

4 COMPUTER GENERATED ISOSEISMAL RADII

In addition, it is useful to indicate on the maps some estimate of the degree of shaking that might be expected. This to some extent replaces the often fairly arbitrary assignment of MMI contours to a very variable data set of MMI values. It can show the correlation, or lack thereof, between expected felt effects, and those interpreted from the submitted forms. Returns which are obviously anomalous, either too high or too low, can then be re-examined to see if there have been any obvious errors in the automated assignment of MMI.

The relationship between magnitude and felt intensities in Australia has been discussed by several authors including Greenhalgh et al (1988), McCue (1980) and Michael-Leiba (1989). Several formulae exist to describe the relationships between the magnitude of an earthquake, the distance from the epicentre, and felt intensity. Here we present a new relationship derived from measurements made from earthquakes in the 'Atlas of isoseismal maps of Australian Earthquakes' Parts 1 and 2 (Everingham et al., 1982 & Rynn et al., 1987) and a few from Part 3 of the Atlas.

The area covered by the isoseismal was measured directly from the map manually. The average area covered by a contour was defined to be the area of the circle with a radius equal to $(R_{max} + R_{min})/2$ (*McCue,* 1980). R_{max} is the maximum distance between the epicentre of the earthquake and any point on the contour and R_{min} is the minimum distance between the epicentre and the contour. R_{max} and R_{min} were found by measuring the contour at a number of possible points (usually about 5 points per contour) and finding the maximum or minimum value. The formulae for the average and maximum radii versus magnitude (ML) were then found by least squares regression.

Figures 1 to 3 show the average radii as a function of magnitude. The derived formulae for the average radius of the level III, IV and V isoseismal were:

$$R^{III}{}_{avg} = (1.9 \pm 0.3) \times (2.38 \pm 0.06)^{ML} \quad (1)$$

$$R^{IV}{}_{avg} = (0.9 \pm 0.3) \times (2.57 \pm 0.07)^{ML} \quad (2)$$

$$R^{V}{}_{avg} = (0.4 \pm 0.5) \times (2.5 \pm 0.1)^{ML} \quad (3)$$

The regression for the maximum distance between the epicentre and the contours for the isoseismal contours III, IV and V were:

$$R^{III}{}_{max} = (2.3 \pm 0.3) \times (2.37 \pm 0.06)^{ML} \quad (4)$$

$$R^{IV}{}_{max} = (1.2 \pm 0.3) \times (2.51 \pm 0.07)^{ML} \quad (5)$$

$$R^{V}{}_{max} = (0.7 \pm 0.5) \times (2.4 \pm 0.1)^{ML} \quad (6)$$

The results of this study are compared with previous studies of Australian earthquakes in Figures 4 and 5. In the magnitude range between 4 and 6, all these studies are in close agreement. This is not surprising since the majority of the data lie within this magnitude range. McCue (1980) and Michael-Leiba (1989) calculate their regression curves using a small number of earthquakes (approximately 20 in both cases) while this study uses between 67-100 (depending of the isoseismal level). Greenhalgh et al. (1989) uses all the earthquakes in Part I and II of the isoseismal atlas, but no earthquakes from Part III.

There is a small difference between McCue's (1980) results and this study's regression curve for small magnitude earthquakes. However, McCue's (1980) regression curve still lies within two standard deviations of the curve found in this study (compare Figures 1 and 4). There is a much larger difference between the regression curve derived in this study and that from Greenhalgh et al. (1989) for low magnitude earthquakes. This is due to the different form of the regression curve assumed by Greenhalgh et al. (1989). There is insufficient data for these low magnitudes to confidently discriminate between these two curves in the magnitude range between 2 and 3. However, if we extrapolate Greenhalgh's et al. (1989) curve, we find that it predicts that no earthquake can be felt below approximately ML 1.6. However, there have been at least two earthquakes at or below 1.6 that have been felt (the 1994 ML 1.0 earthquake in Canberra and the 1976 ML 1.3 Preston earthquake in Melbourne).

Both earthquakes actually caused intensities as high as IV. Therefore the regression curve used in this study has the advantage of being both simpler than Greenhalgh's et al. (1989) curve and a bit more consistent with the data.

Figures 6 and 7 show our results compared to those from similar studies done for North American earthquakes. The differences between our results and those in North America are mostly within two standard deviations of our regression curve. The exception is the curve from Sibol et al. (1987) which has a similar curve to that from Greenhalgh et al. (1989) and thus does not agree with our curve for small magnitudes. The curve from Sibol et al. (1987) also predicts a slightly bigger radius for large magnitude quakes than our curve.

5.0 RESULTS OF THE METHOD FOR EIGHT AUSTRALIAN EARTHQUAKES

The results of applying the methodology listed above to the seven earthquakes indicated in Table 4, plus the Eugowra earthquake of 1994, are shown on Figures 8 to 15. Isoseismal radii, computed from the formulae for average isoseismal radii (formulae 1, 2 and 3 above) were added to the figures. The plots were produced using the Unix program, G.M.T.

6.0 CONCLUSION

It is possible to automate the processing of data from existing on-line felt report forms. However, a lot of simplifications have to be made to do this, and a lot of refinement is still required. A better designed form, possibly similar to the USGS "DYFI" form, would make processing much easier, and a collaborative effort between the relevant Australian seismological agencies is probably required.

The maps presented here have been enhanced by plotting expected isoseismal radii, using new formulae prepared from a review of published Australian isoseismal maps.

More effort should be made to inform the public that on-line reporting of felt effects is available, and they should be encouraged to use the service. Public participation in the program would probably increase if maps of felt effects were generated rapidly and available on-line to the wider community relatively soon after the event.

Design of the ideal on-line form is not likely to be achieved quickly, and although collaboration is required, a single form to be used by all agencies may not produce the best result.

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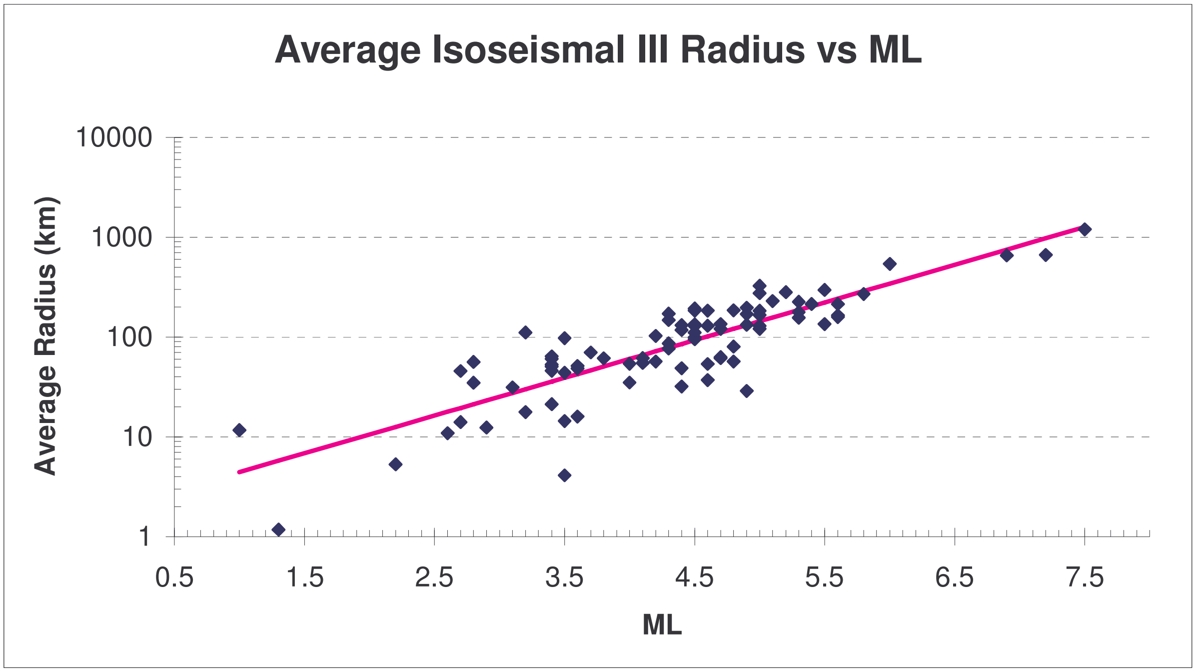


Figure 1: Average radius covered by isoseismal containing all felt reports with a Modified Mercalli intensity above III versus the local magnitude of the earthquake. The solid line through the middle of the data points is the least squares regression curve.

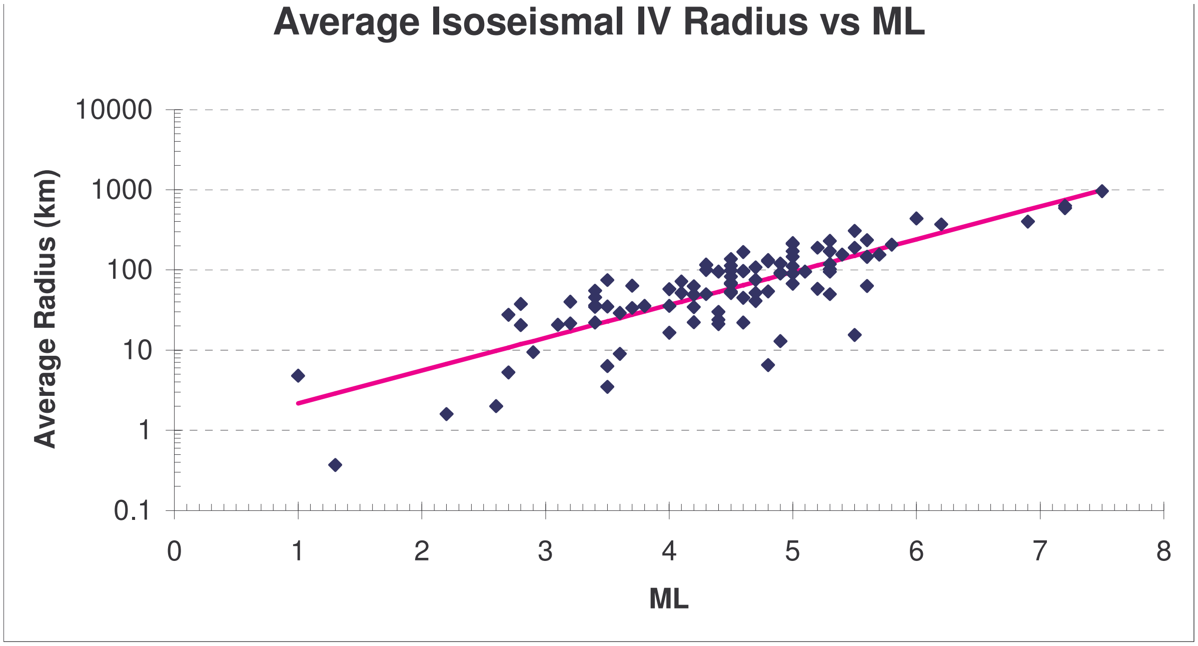


Figure 2: Average radius of the area covered by Isoseismal IVand the least squares regression curve.

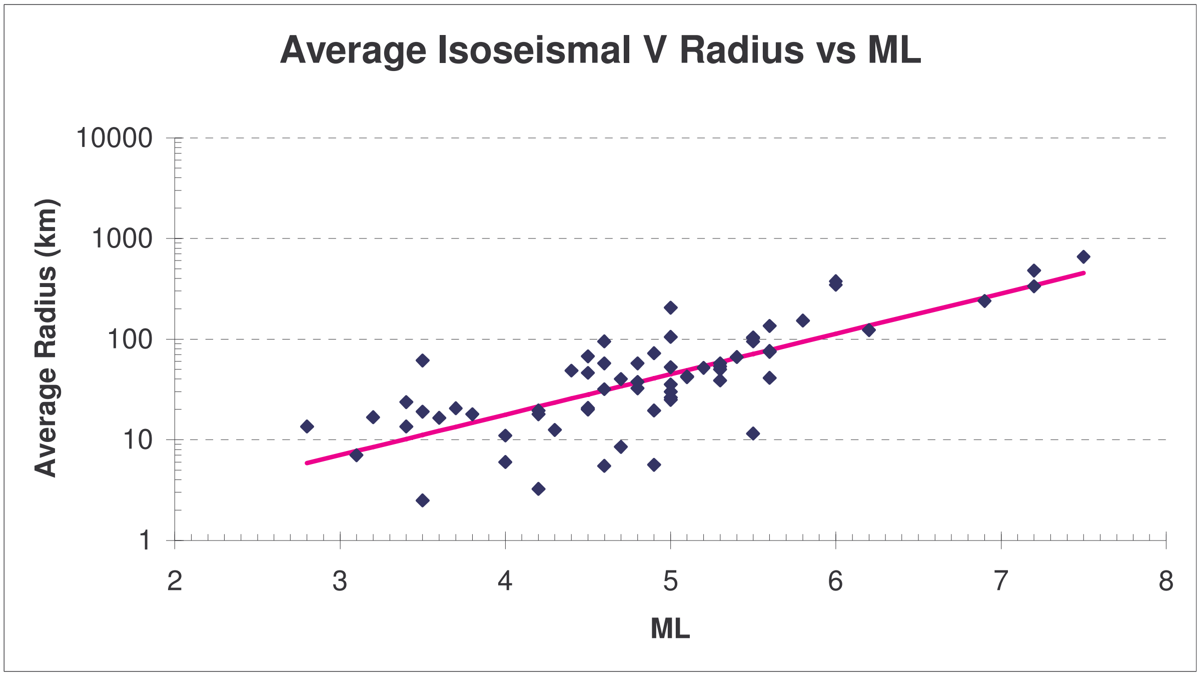


Figure 3: Average radius of the area covered by Isoseismal V and the least squares regression curve.

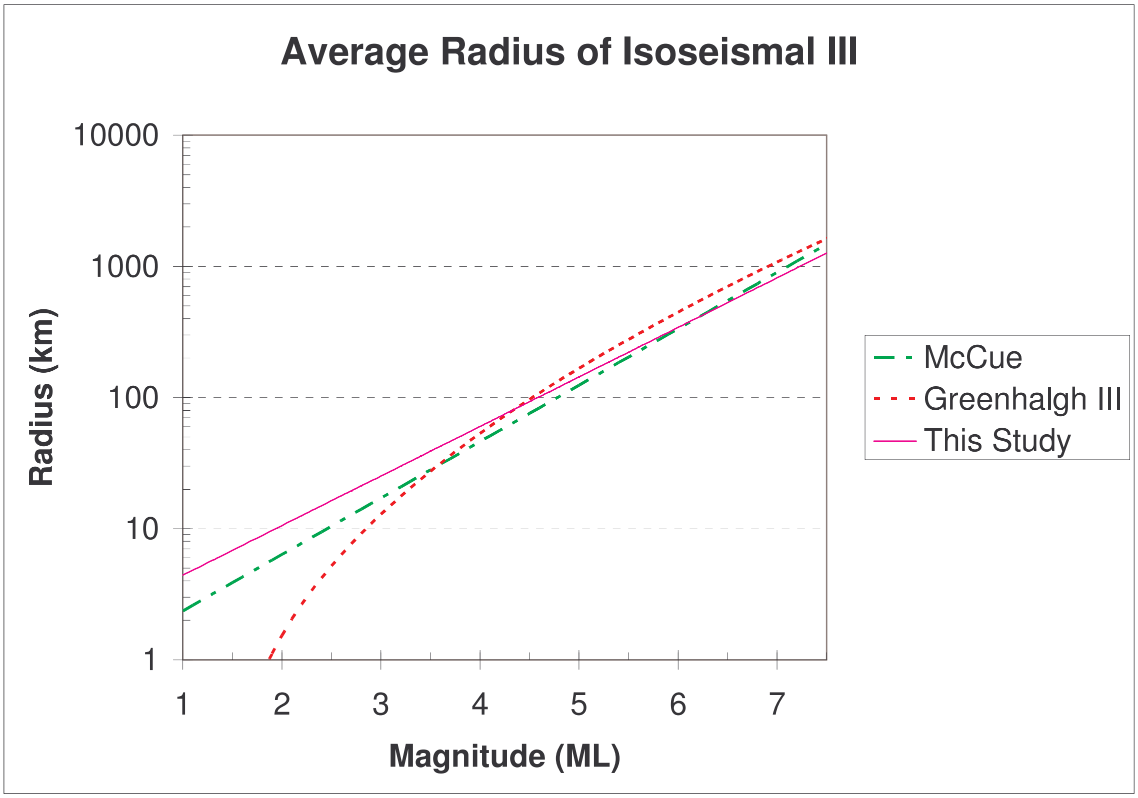


Figure 4: Comparison between the relation derived in this study versus those found in previous studies of Australian earthquakes (*McCue*, *1980* and *Greenhalgh et al.*, 1989) for average radius of the isoseismal III contour.

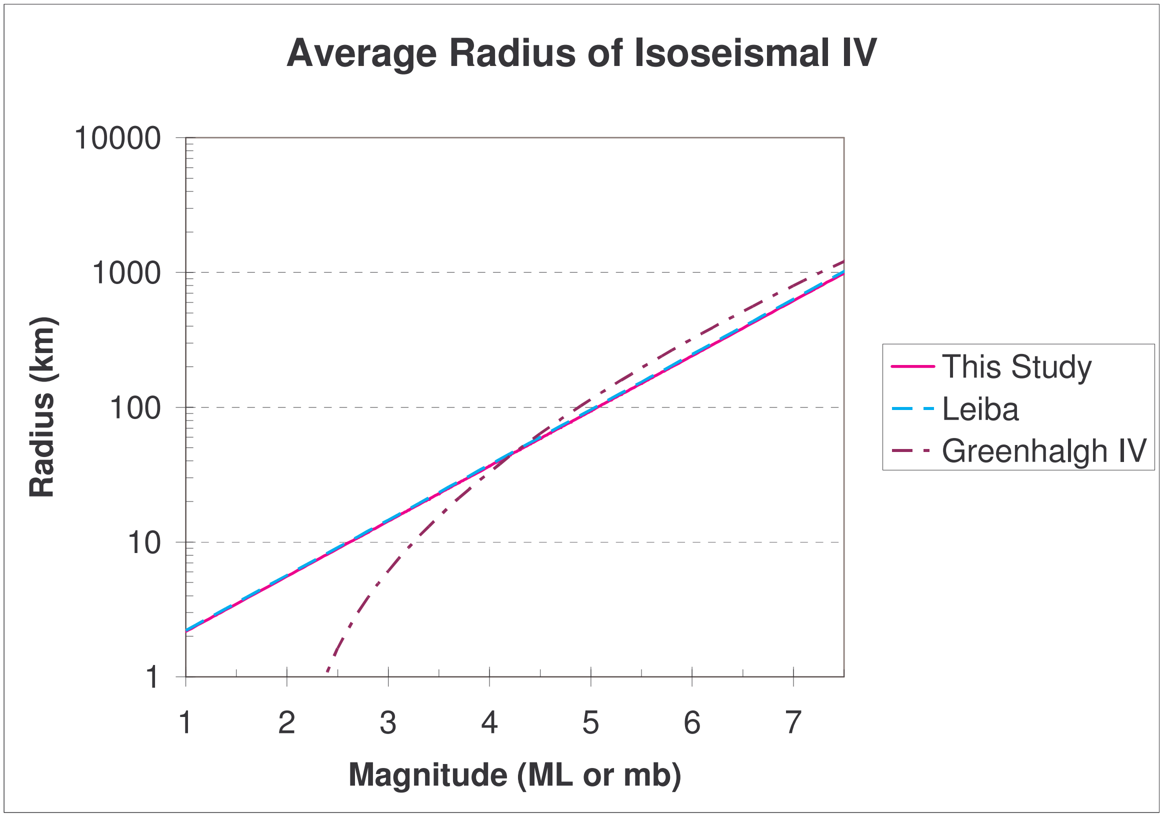


Figure 5: Comparison between the results of this study and those of *Michael-Leiba* (1989) and *Greenhalgh et al.* (1989) for the average radius of the isoseismal IV contour.

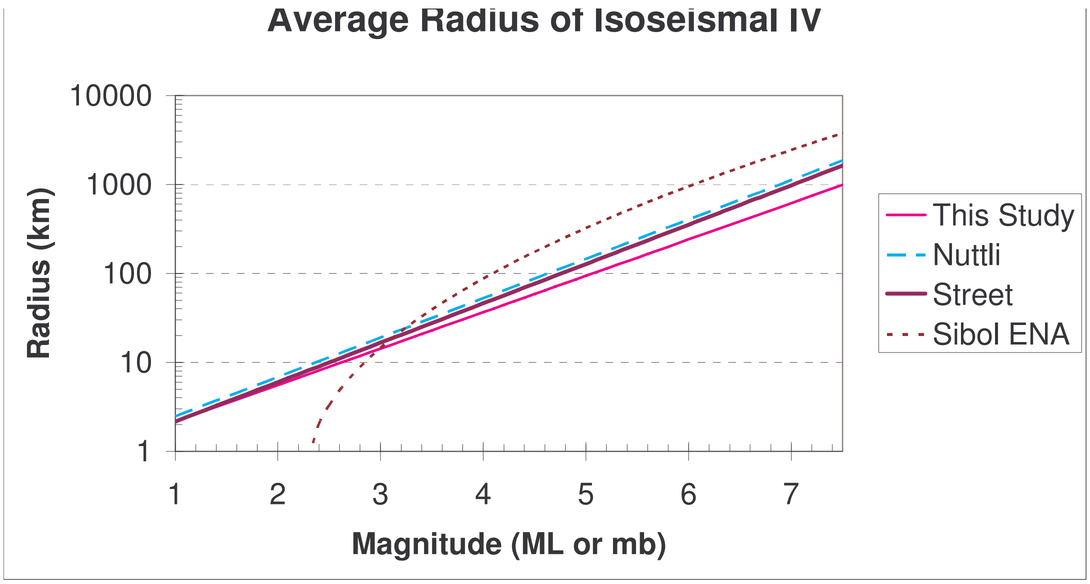


Figure 6: Comparison between the results of this study and studies of North America intensity relations. Note that all the North American relations relate body wave magnitude (mb) to the average area, while this study relates ML to the radius of a circle with the same average area as that inside an isoseismal contour. ML and mb values for the same earthquake can differ from each other by as much as half a magnitude unit (*McGregor & Ripper,* 1976). The "Nuttli" curve used earthquakes from Western and Central North America (*Nuttli et al,* 1979). The 'Street' curve used earthquakes in Northeastern North America (*Street & Turcotte,* 1977) and the Sibol ENA curve used earthquakes from Eastern North America (*Sibol et al,* 1987).

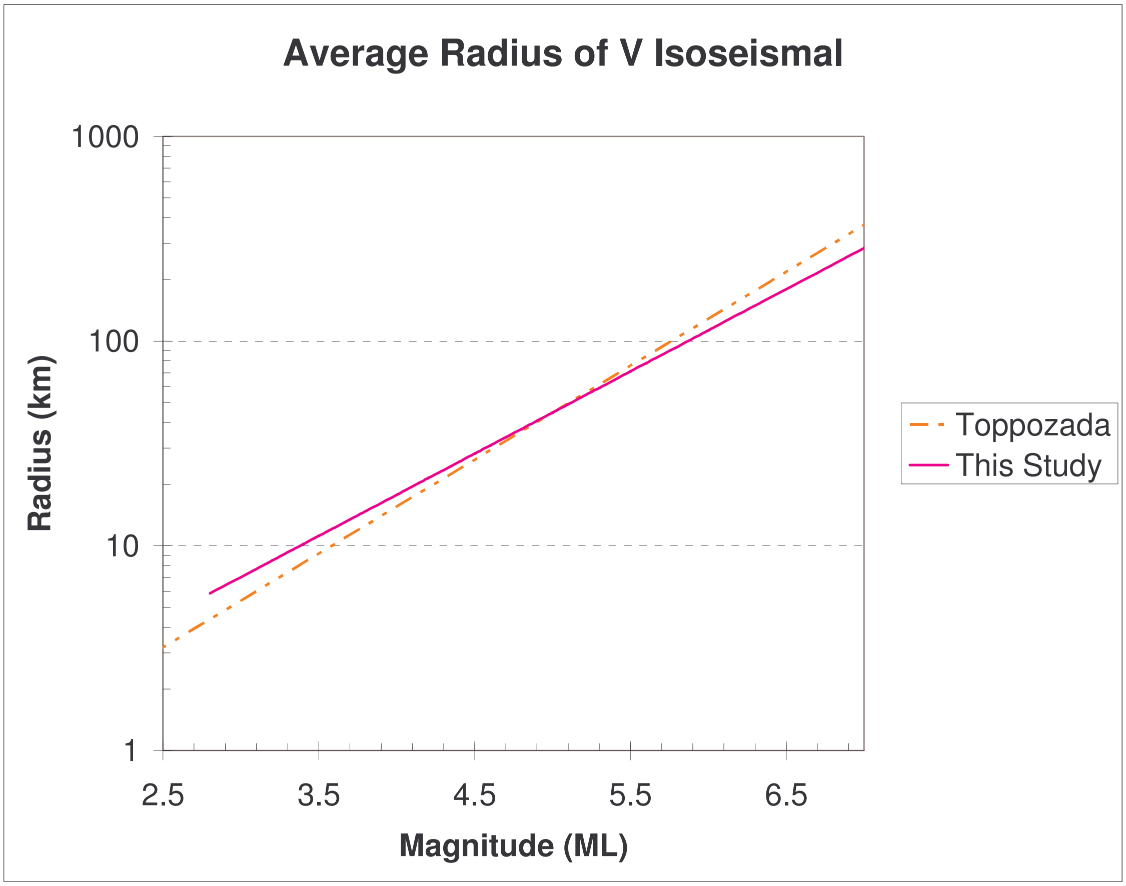


Figure 7: Comparison between the regression curve obtained in this study and that from *Toppozada* (1975) which used earthquakes in California and Western Nevada (both relations use the ML scale).

Bowral Dec 2003, Mag 4.2

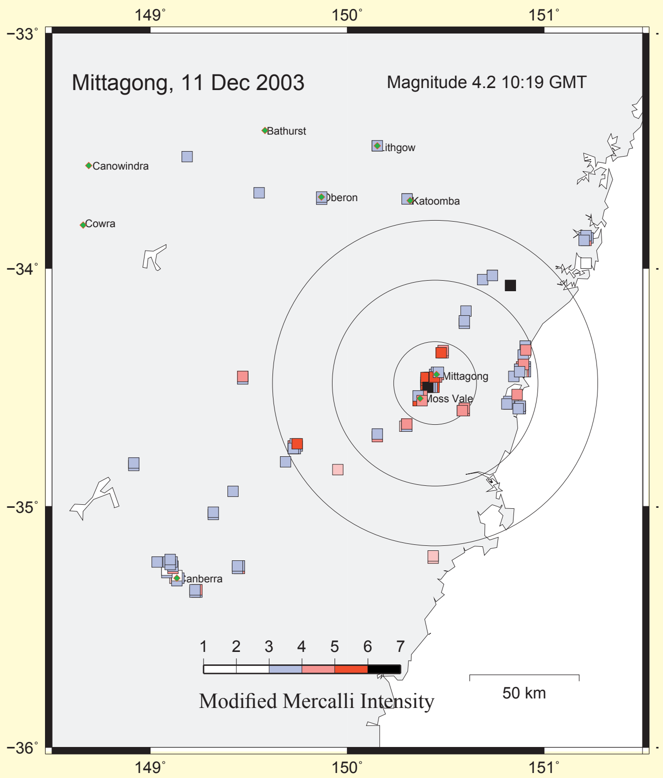


Figure 8

Shark Bay, WA, Feb 2007, Mag 5.3

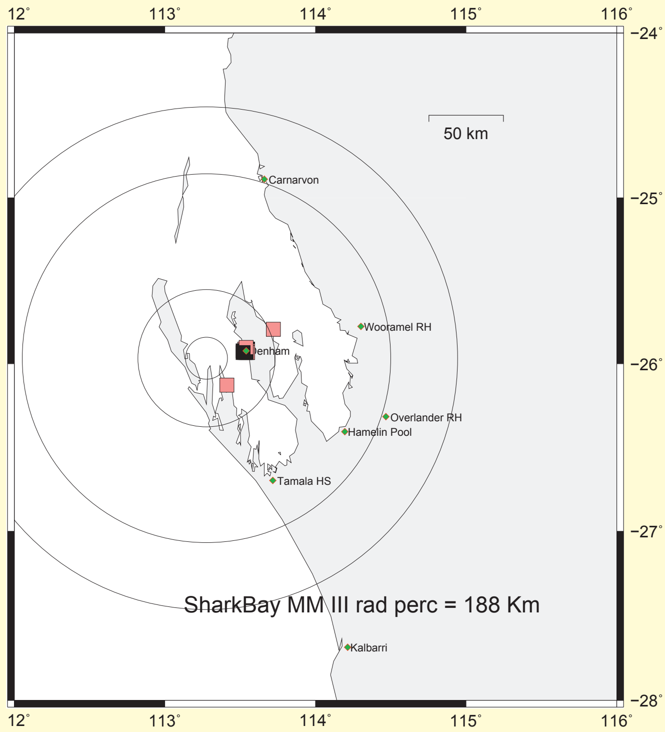


Figure 9

Lithgow NSW, 01 Nov 2005, Mag 3.1

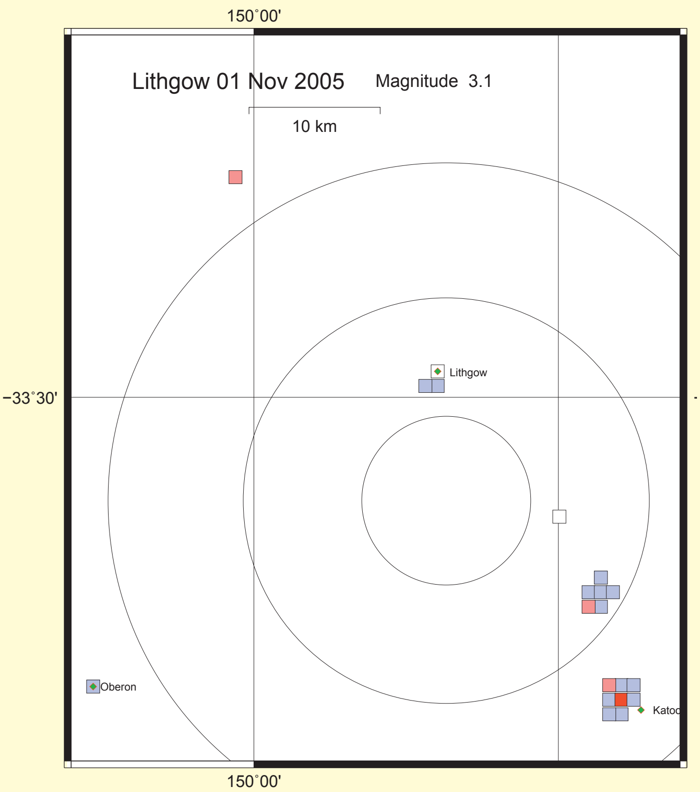


Figure 10

Melbourne, Vic 22 Oct 2006, Mag 2.9

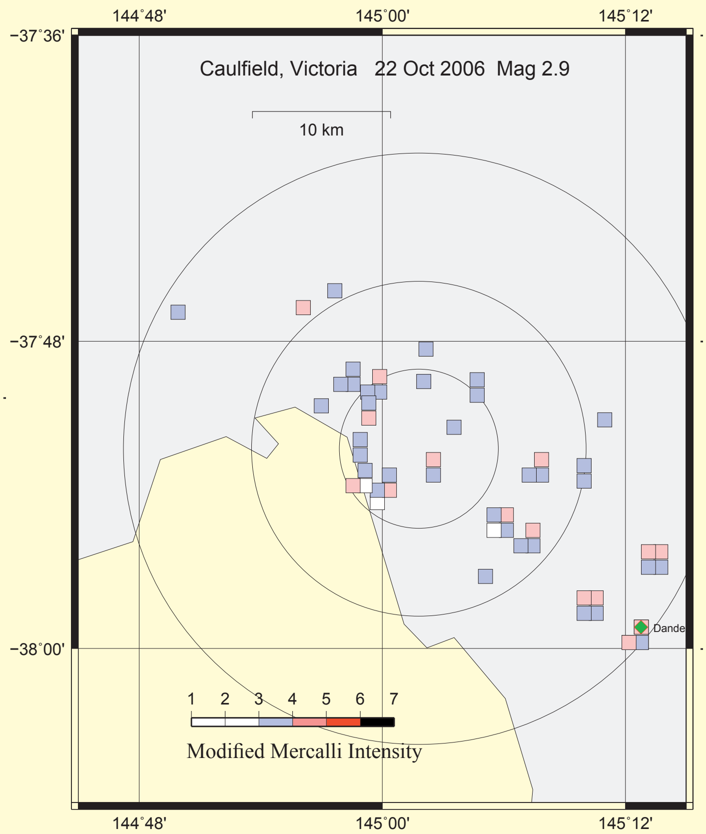


Figure 11

Cowra, 21 Oct 2006, Mag 4.2

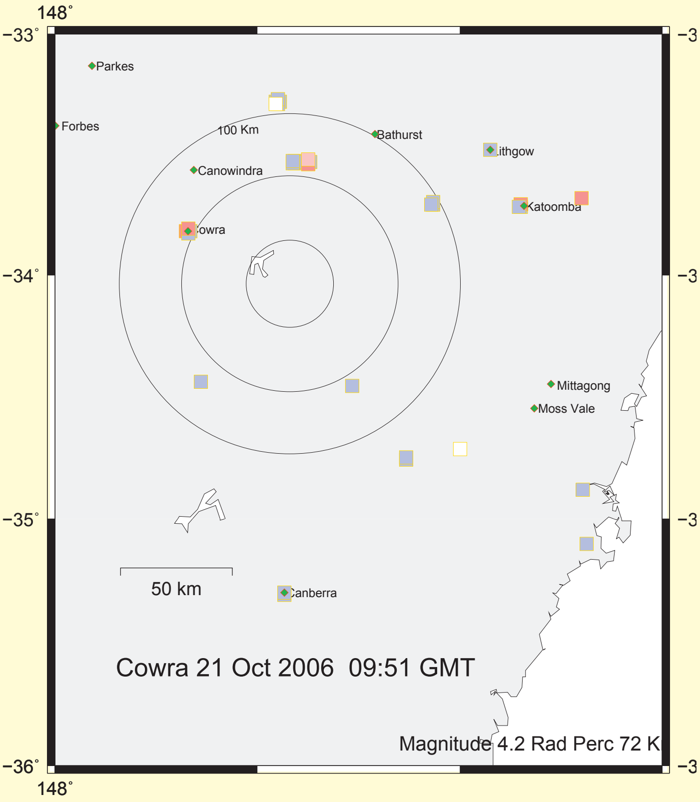


Figure 12

Warburton Vic, 8 March 2007, Mag 3.5

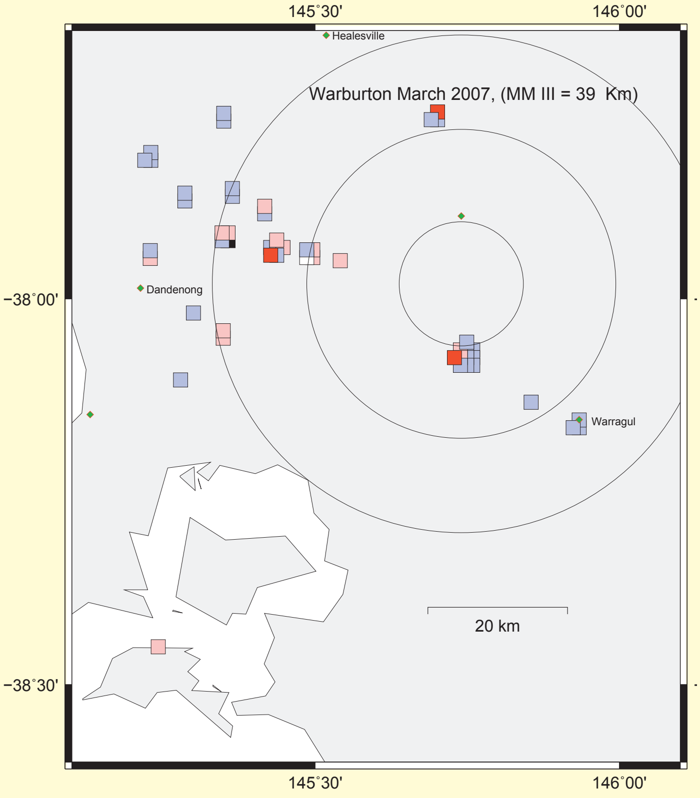
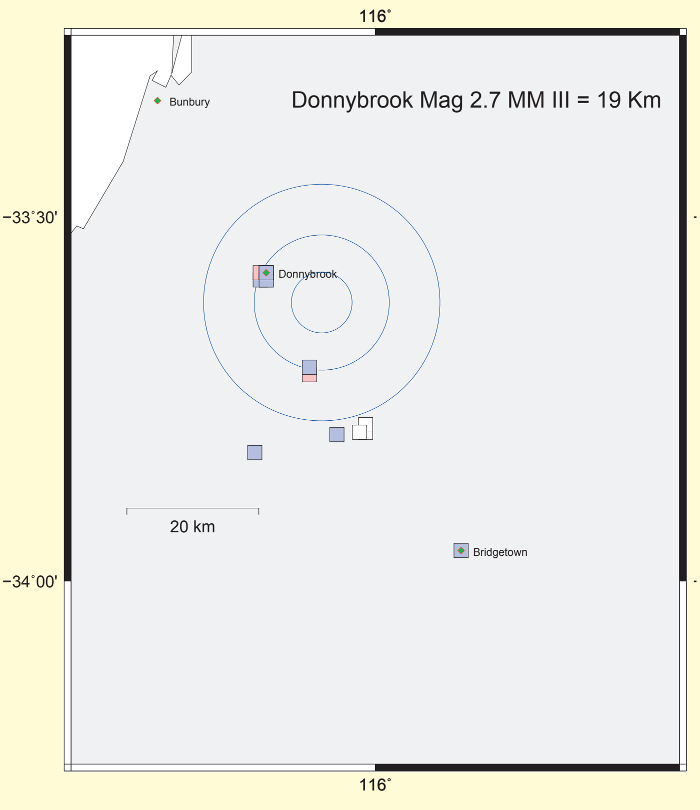


Figure 13

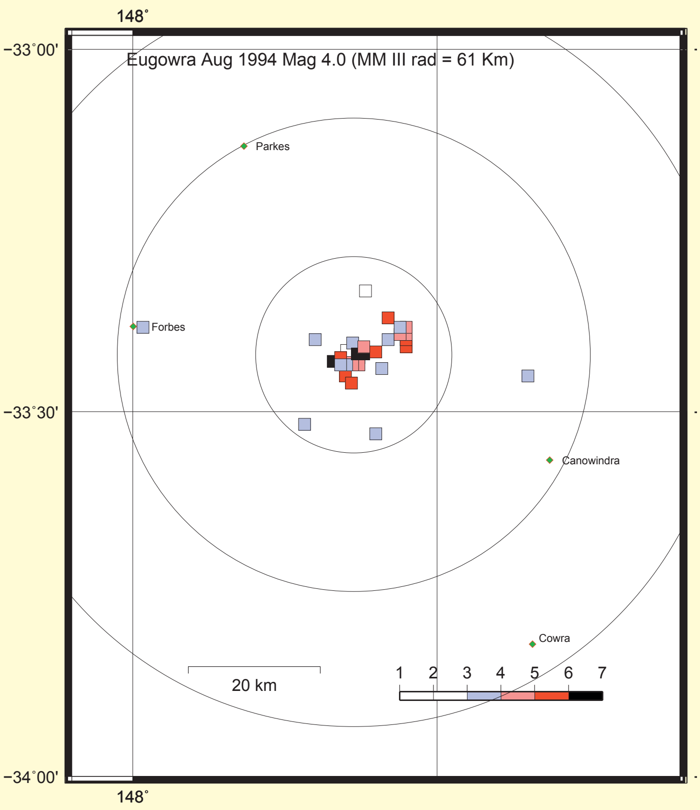
Donnybrook WA, 5 March 2006, Mag 2.7



* UWA data

Figure 14

Eugowra NSW, Aug 1994, Mag 4.0



** Data from posted questionnaires

Figure 15