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Spatial and temporal variation of seismicity across Australia

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Abstract: *A first attempt has been made to quantify the variability in the seismic activity rate across the whole of Australia. Using the AGSO Earthquake Database (Lenz et al., 1992) updated to 1997, the most complete catalogue of Australian earthquakes to date, and the software tool ZMAP, spatial and temporal variations of the seismicity across the continent have been computed. Since the start of instrumental recording at the beginning of the century moment release rate in continental Australia has been fairly constant with a pseudo periodicity in seismic moment release with a period of about 20-25 years. The 'b' value relating the number of large to small earthquakes over the whole area is estimated to be 0.94 ± 0.15 for events with* $M_L \geq 4$ *in the period 1902-1997. The mapped 'b' value varies dramatically from decade to decade but taking the whole century, we seem to have a region of high 'b' traversing north-south through the centre of the continent which is indicative of an area of high stress. An Alarm Cube, which highlights areas where there has been a significant drop in the seismicity rate, highlights two zones in the SE of the country. This anomaly in the most densely populated region has persisted since approximately 1985.*

Key Words*: Seismic Rate, 'b' value, Stress, Earthquake Catalogue, Australia.*

INTRODUCTION

Documentation of significant seismic events in Australia commenced with the first European settlement of the continent at the end of 18th century, and the first instrumental records became available from the beginning of the twentieth century. However, not until the deployment of the first modern short period seismic networks in the early 1960s was reasonable coverage of continent-wide seismicity attained. The vast sparsely populated area and decentralisation of institutions involved in monitoring seismic activity for the better part of the last 100 years has made the task of creating a homogeneous catalogue of Australian earthquakes quite difficult. Only recently has a more complete continent-wide data set been assembled for events with $M_L \geq 4.0$ since 1900. The current target level of detectability across the country is magnitude 3.0. All these factors have mitigated against the study of the spatial and temporal variation of seismicity across the continent. Known active zones in the country have however been investigated in separate studies (Doyle *et al*., 1968; McCue *et al*., 1989, 1990, 1990, 1992; McCue and Michael-Leiba, 1993; Gibson *et al*., 1990; Jones *et al*., 1991; Michael-Leiba *et al*., 1994; Spassov *et al*., 1997). In these studies the 'b' value of the Guthenberg-Richter relation has been estimated to be close to 1.0.

DATA AND METHOD

A catalogue of nearly 10,000 earthquakes with magnitudes between M_L 2.0 and M_L 7.2 since 1841 is the basis of the present study. Since most of the events with magnitude below 3.0 have been recorded in the last two decades in areas with good station coverage, only events with $M_L \geq 3.0$ have been used for the study. The spatial distribution of these events is presented in Figure 1. Earthquakes with magnitude greater than 6.6 are highlighted together with the date of their occurrence. The largest event (1906, M=7.2) was off the west coast of Western Australia, but its location is within the continental crust (Fig. 1.).

Since instrumental recording started at the beginning of this century, and because the catalogue is most complete for events with $M_L \geq 4.0$ (McFadden *et al*., 2000), these parameters have been used for the evaluation and mapping of 'b' values across the continent. The entire catalogue is used for the rest of the study.

Our investigation of the spatial and temporal variations of seismic activity across the country is based on the seismic tool ZMAP. ZMAP is a software package tool for investigation of seismic quiescence and artificial seismic rate changes. The theoretical basis of the software is presented in Wiemer and Wyss (1994, 1997) while the coding is given in Wiemer (1996). ZMAP allows a custom selection of the size of the grid: latitudinal and longitudinal distance between grid points (grid spacing) in degrees as well as of the number of events per grid point. There is a trade off between the significance of the calculated values and the resolution. Small volumes, meaning few earthquakes, result in less significant values but a good spatial resolution, and vice versa. Considering the scarce number of earthquakes in some regions in Australia we decided to start with 1 by 1 geographical degree cells. Still, because of the relatively low reliability of the 'b' values in some cells we can only comment on the results in a qualitative, rather than quantitative way.

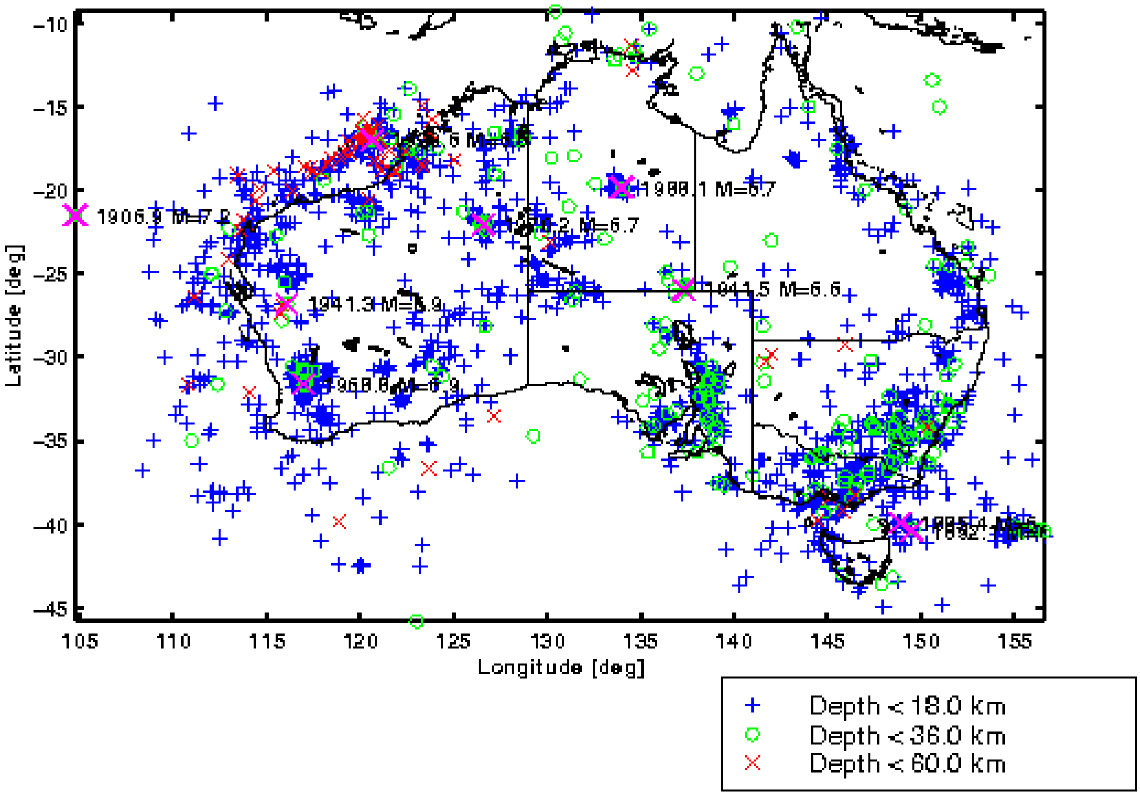


FIG. 1. Distribution of Australian Earthquakes with $M_L \geq 3$ from 1902 to 1997: the events with $M_L \geq 6.7$ are presented with a larger cross and the date of their occurrence.

This program provides a wide range of tools available to study the seismicity, and these can be classified under four main topics: 1) seismicity rate changes and precursory quiescence; 2) catalogue homogeneity and reduction of artificially introduced seismicity rate changes; 3) visualisation of the frequency-magnitude distribution in space and 4) earthquake clustering.

RESULTS AND DISCUSSION

Figure 2 presents the time distribution of the cumulative number of events of magnitude 3.5 or more (left graph) and cumulative moment release (right graph). They show a relatively steady rate of occurrence of strong events (with some time clustering) and a significant increase in the total number of recorded earthquakes as the number and sensitivity of seismographs has increased. The cumulative moment graph shows a pseudo periodicity with a period of 20 - 25 years. The most recent cumulative moment release jump occurred in 1988.

ZMAP was utilised as a tool to perform the framework statistics. It permitted interactive event selection in polygons of any shape. We used rectangular cells varying the size between 1x1 and 5x5 geographical degrees. The separation of the independent part of the seismicity (declustering) was also attempted through the program. The conclusive evaluation of seismicity rate changes as a function of space and time was expressed in terms of a standard deviate *z*. The standard deviate *z* describes the significance of the rate change and is plotted last in a so called *Alarm Cube*.

The frequency-magnitude plot used to estimate the parameter 'b' in the period 1902 - 1997 is shown in Figure 3. For events with magnitude greater than 4.0, the 'b' value is 0.94 ± 0.15 which is within the expected range. There is some indication of rolloff below magnitude 4.5 above which the catalogue can be considered complete since about the beginning of this century. This was when instruments were first installed and the population in Australia had become sufficiently large and widely distributed that felt earthquakes were routinely reported in local and regional newspapers.

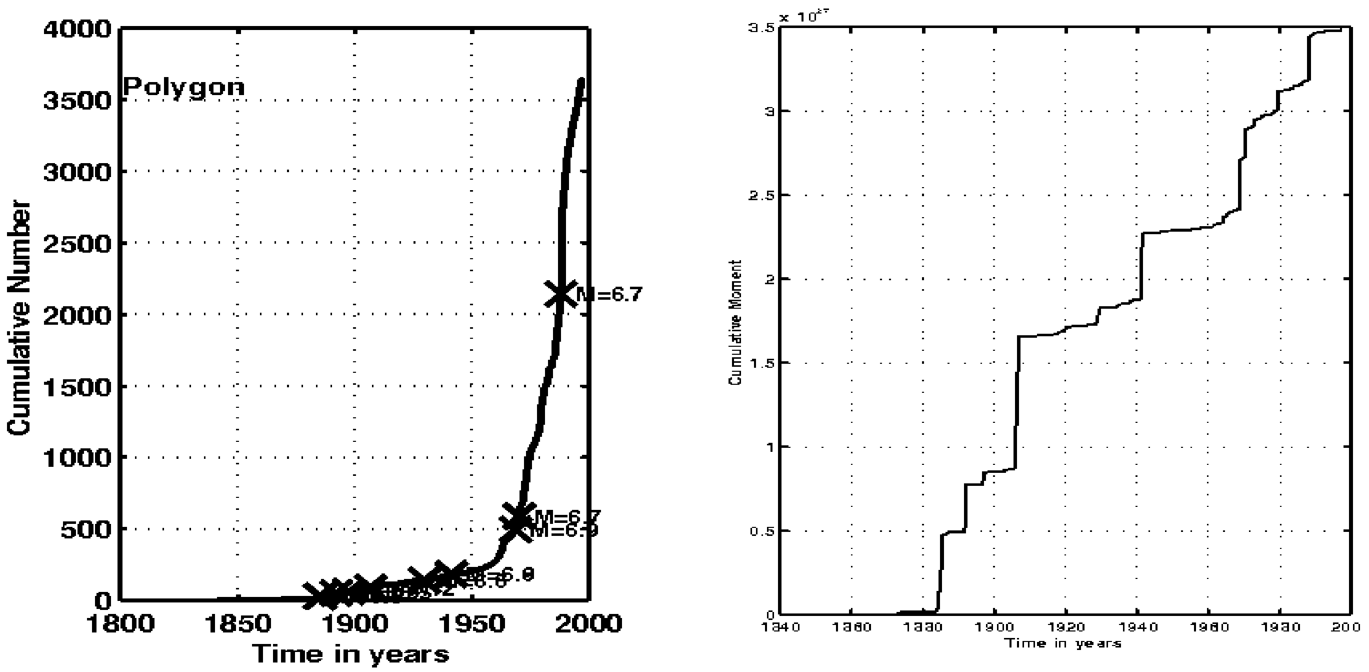
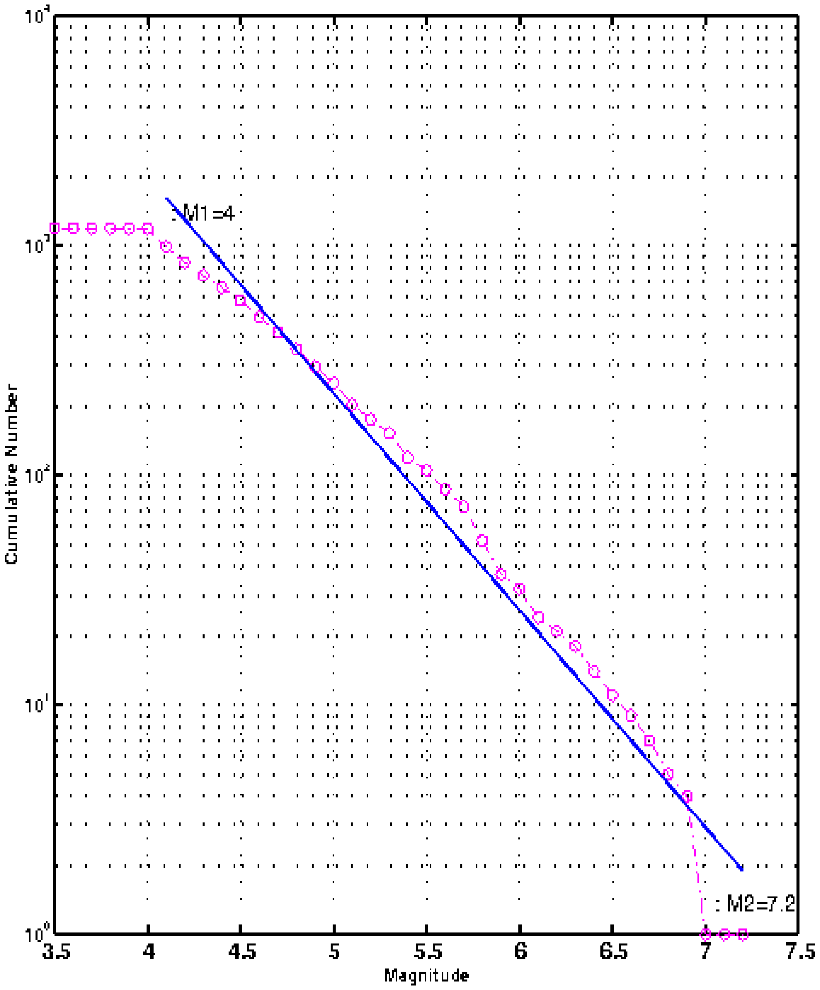


FIG. 2. Time distribution of the cumulative moment (right graph) and number of events (left graph) for the same events as in Figure 1.



B-Value: 0.94 Standard Devration: 0.15

FIG. 3. 'b' value for events with $M_L \geq 4$ - from 1902 to 1997.

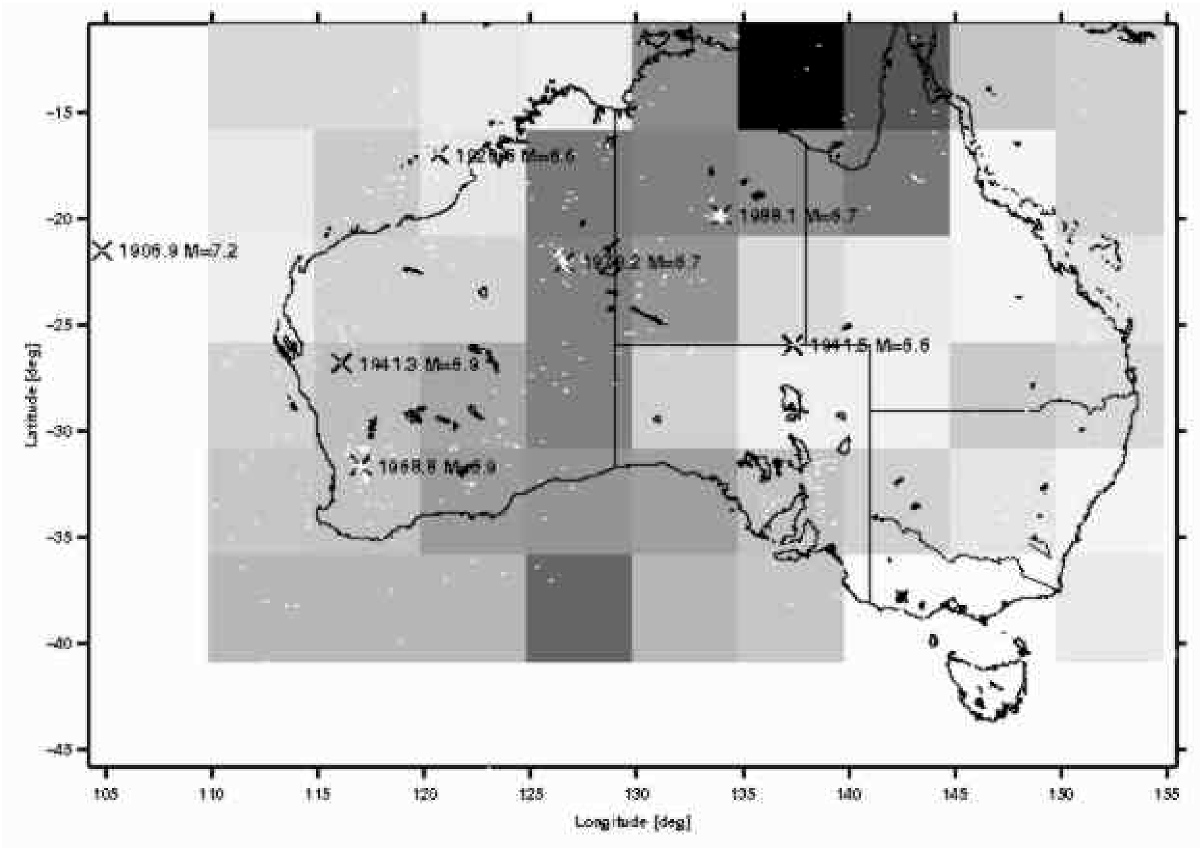


FIG. 4. 'b' value map of Australia for events with $M_L \geq 4$, 1900 to 1997.

That gave us reasonable grounds for using the same data for mapping 'b' across the continent. Figure 4 is such a map for this century in 45 cells with size 5^o x 5^o.

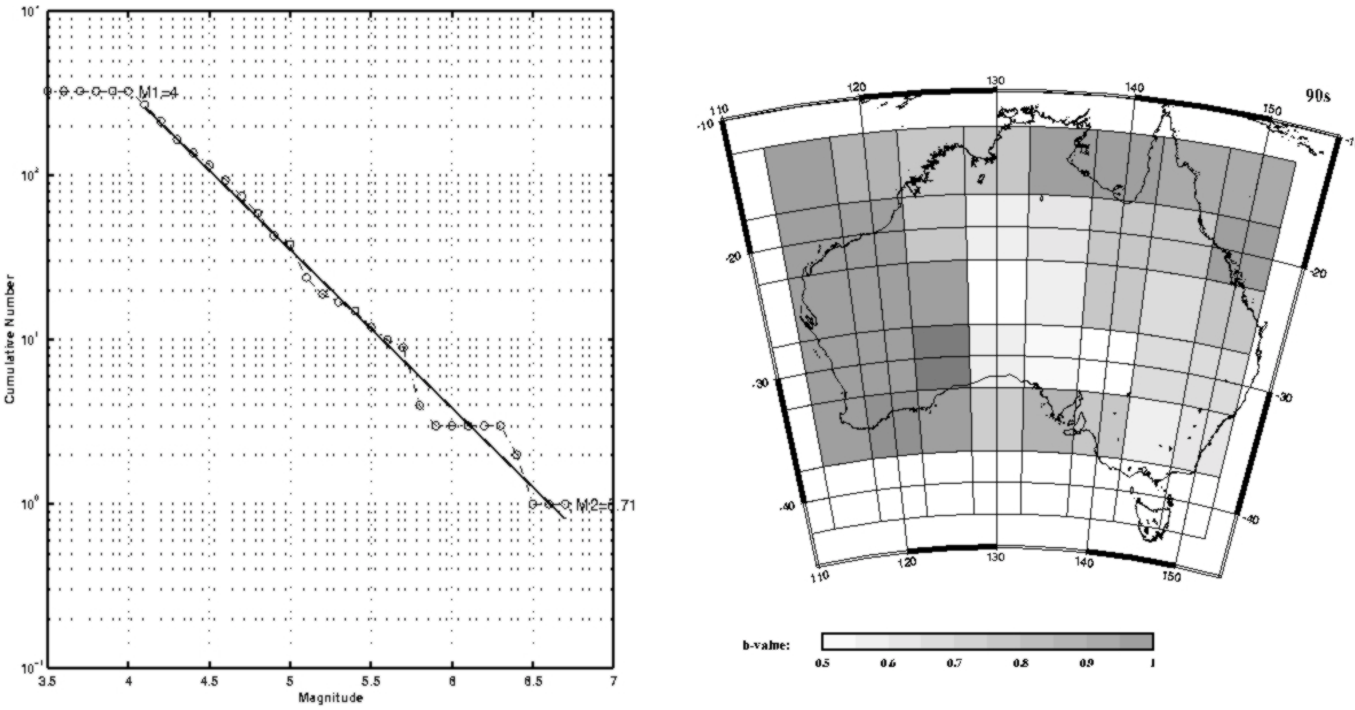
There is a band of high 'b' values trending north-south through the centre of the continent with lower 'b' values in adjacent areas to the east and west. The high 'b' corridor includes the Tennant Creek area of the Northern Territory, apparently seismically inactive up to 1987. A striking earthquake sequence occurred in this zone starting in January 1987, culminating on 22 January 1988 with three earthquakes exceeding magnitude 6 in a 12 hour period. The aftershock sequence has continued through 1997.

Figure 5a shows the 'b' estimate for the ten years 1988 – 1997 (about 300 events). Its value 0.96 ± 0.08 is identical within the uncertainty to the average value over the whole period as shown in Figure 3. The significant deviation of data from the straight line is most probably due to the difficulties in isolating foreshocks and aftershocks in the 1988 Tennant Creek sequence of earthquakes. Figure 5b is the 'b' map for the same time period. This figure shows almost the converse of the one for the whole period with a low value corridor through the middle of the continent flanked by high values to the east and west.

Figure 6a shows the 'b' value estimate for the period 1978 – 1987 (about 200 events).Its value 0.81 ± 0.07 is significantly lowers than that of the whole period and there were few large events in this period. The 'b' value map for the same time period is presented in Figure 6b. The central part of the continent shows an anomalously low 'b', while the highest values are concentrated in the S-SE of the country. Several events with magnitude greater than 6.0 occurred in the western part of the continent in this period but no significant events were recorded in the south-east and only one earthquake with M_L 6.2 occurred at Marryat Creek in South Australia, in the middle of the low 'b' area.

Figure 7a shows the 'b' value of 0.93 ± 0.10 for the time period 1968 – 1977 (about 200 events), nearly identical to the 'b' value for the century. This is also the time-slice with the larger number of strong events in the central and western parts of the continent. The 'b' map of the period is shown in Figure 7b. The centre of the country now shows higher than average 'b' value, while the lowest 'b ' is in the west.

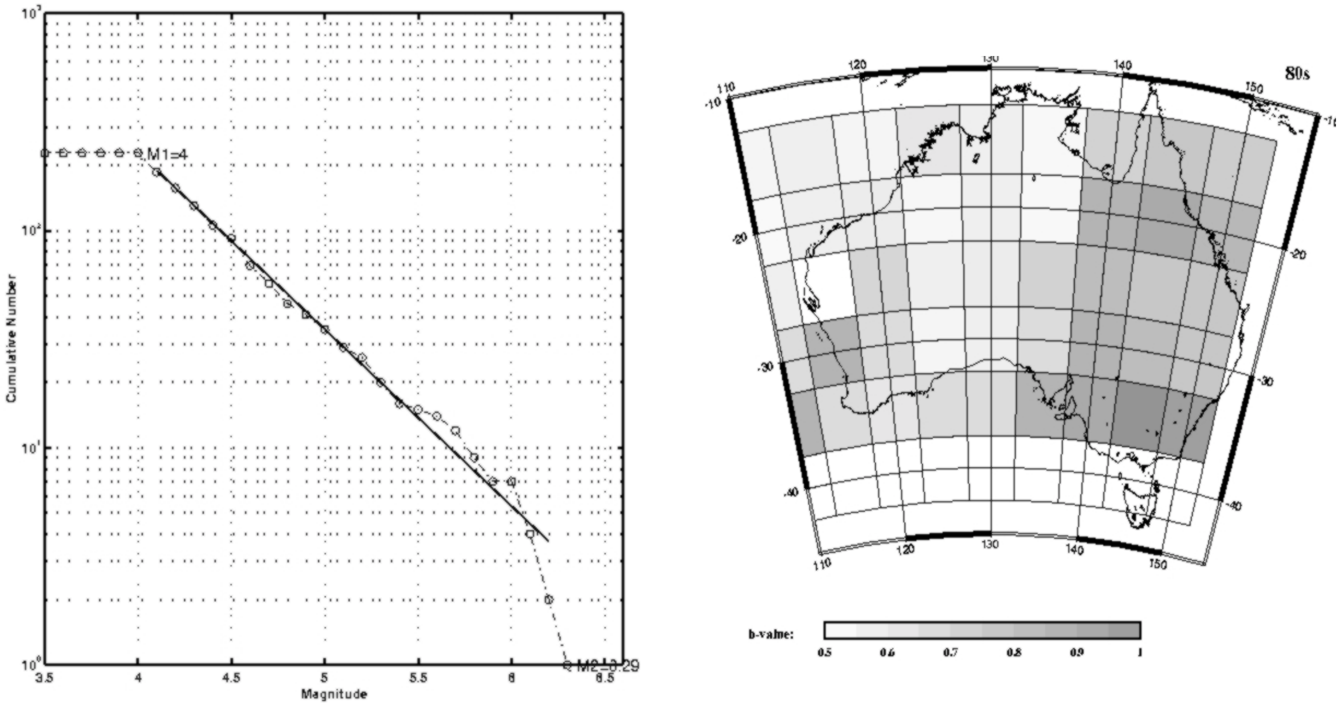
The data show large deviations about the straight line in the magnitude-frequency relation for the period 1958 - 1967 (around 100 events) as shown in Figure 8a, though the value of 'b' 0.90 ± 0.15 is very close to that for the whole period, established earlier (Fig. 3). This data deviation can be attributed to scatter in the computation of magnitude and the sparsity of the seismic networks up to half way through this time slice. The 'b' value map (Fig. 8b) is also more complex with the areas of lowest and highest 'b' together in the centre of the country. The only two significant events during this period (with $M_L \geq$ 6.0) occurred in the north-western part of the country.



B-Value: 0.98
Standard Deviation: 0.03

a) **b)**

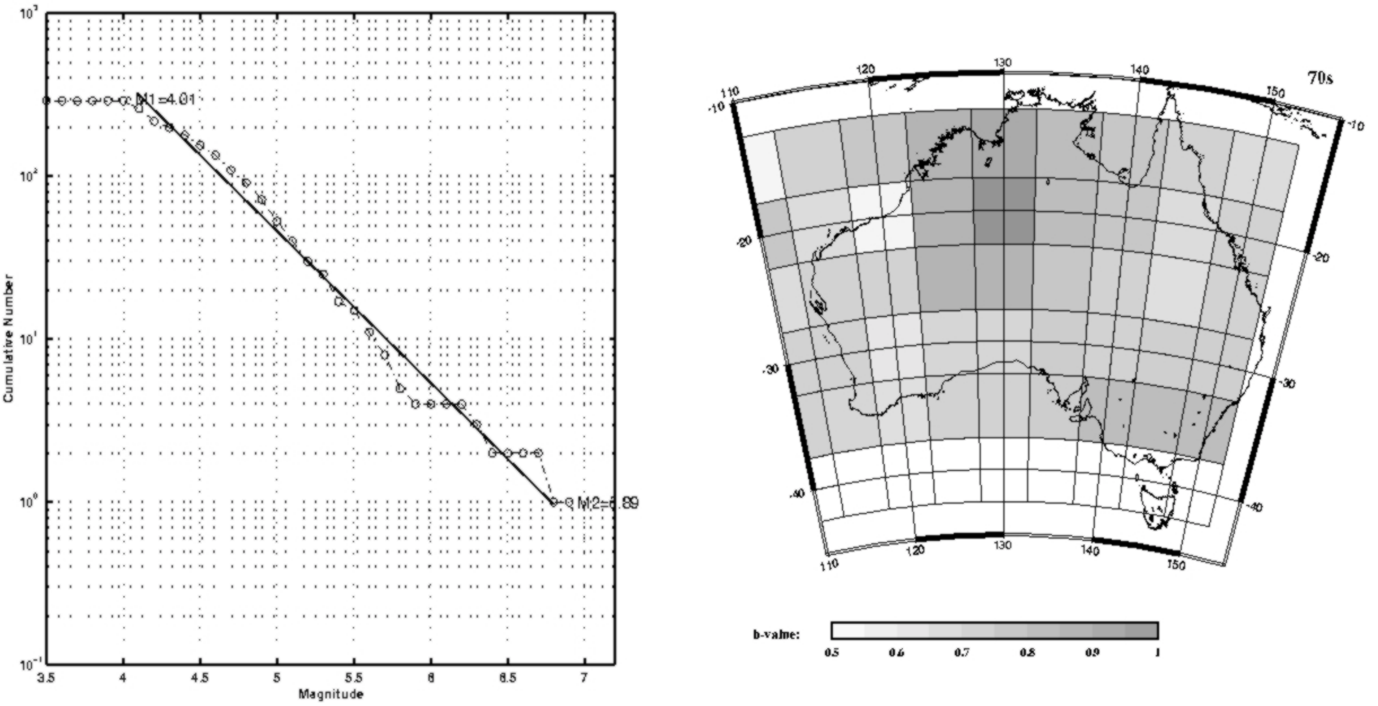
FIG. 5. 'b' value for events with $M_L \geq 4$, 1988 to 1997.



B-Value: 0.91
Standard Deviation: 0.07

a) **b)**

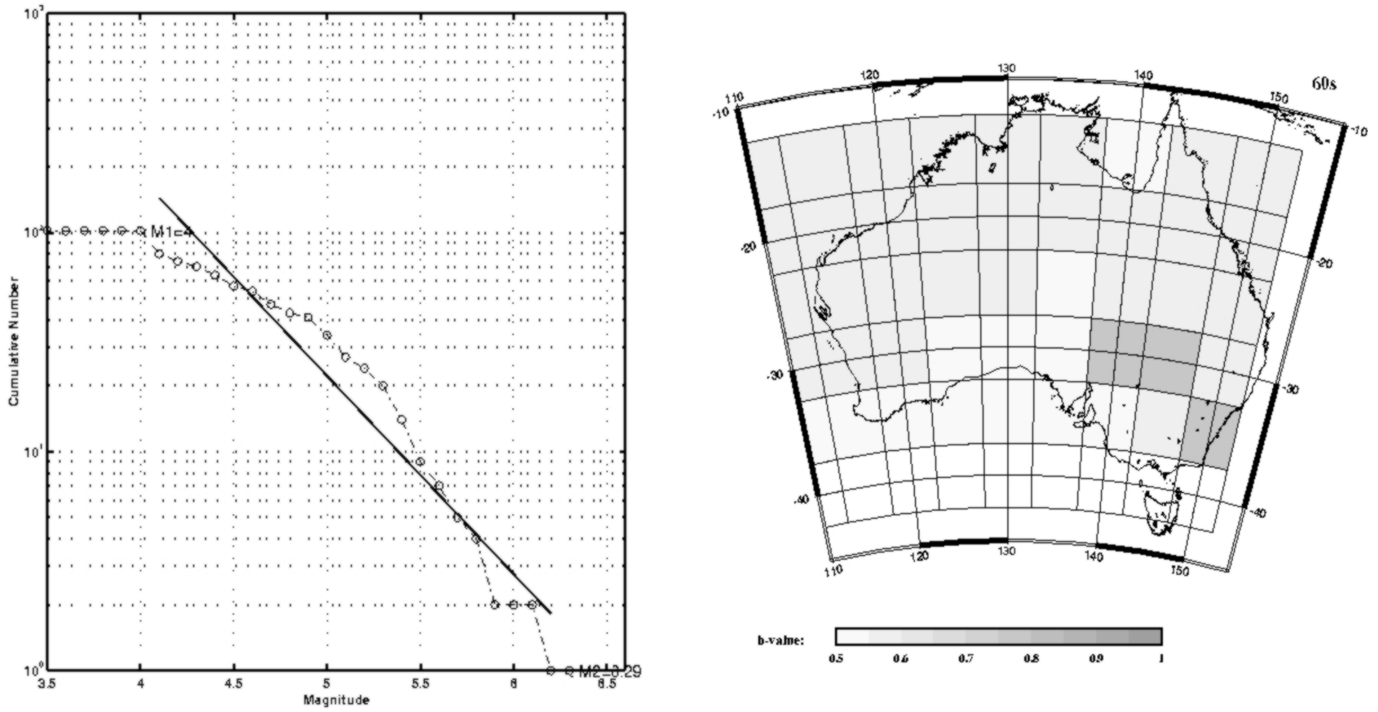
FIG. 6. 'b' value for events with $M_L \geq 4$, 1978 to 1987.



B-Value: 0.93
Standard Deviation: 0.1

a) **b)**

FIG. 7. 'b' value for events with $M_L \geq 4$, 1968 to 1977.



B-Value: 0.90
Standard Deviation: 0.15

a) **b)**

FIG. 8.. 'b' value for events with $M_L \geq 4$, 1958 to 1967.

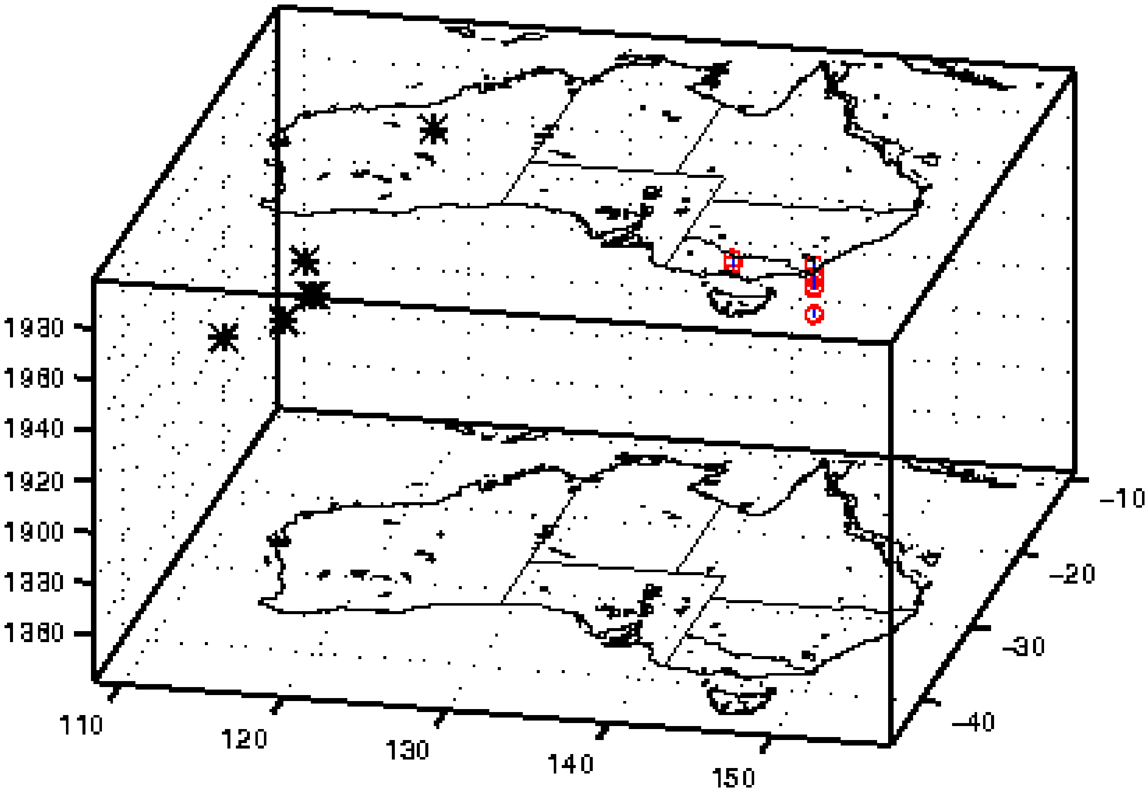


FIG. 9. Alarm Cube of the zones with anomalous decrease in seismic rate in Australia.

Figure 9, the Alarm Cube (Wiemer, 1996), reveals areas with a significant decrease of seismic activity. The Alarm Cube analysis is based on SEISMOLAP as proposed by Zschau (1995) and measures the overlap of earthquakes in space and time. The elegance of the method is that clustering of earthquakes as well as seismic quiescence at one location can be measured with one variable. The alarm cube is a first attempt to visualize anomalous seismicity rate decreases in time and space in one figure. Z-value maps for all times are calculated using either the LTA or the rubberband function. An alarm is issued when a z-value exceeds a threshold that can be set in the lower right corner of the alarm cube window. The minimum possible threshold is z = 2.57. Each alarm is plotted as a circle in the space-time cube.

For Australia the Cube has been drawn for all events with $M_L \geq 3$ from the beginning of the catalogue i.e. 1841. Two anomalous areas are highlighted. One of these areas is near the Victoria-NSW border and the apparent drop of seismic rate started approximately around 1980. The second anomalous zone is in the vicinity of Melbourne and its timing is very recent - in the last few years. Although a quasi periodicity in the significant seismic moment release of about 20-25 years have been observed earlier in this study, it is not possible at present to relate this periodicity to the anomalous zone since no territorial correlation of the pseudo periodicity has been established.

CONCLUSION

A first quantitative study of the spatial distribution of the seismicity rate across continental Australia has been performed. A concentration of low 'b' (supposedly increased stress) is identified in the centre of the continent during the last two decades. Areas with generally higher 'b' flank this central area. The time variation of seismic activity shows a pseudo periodicity with a period of about 20 -25 years in both the release of strong events and territorially.

Two zones with an apparently significant lack of seismic activity have been identified in the SE of the country. Both zones are in a close proximity with the most densely populated areas of Australia.

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