Preliminary test of the EEPAS long term earthquake forecast model in Australia

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Abstract

EEPAS is a long term earthquake forecasting procedure (Every Earthquake a Precursor According to Scale) developed by Evison and Rhoades. To date, the EEPAS procedure has been successfully tested in the tectonically active regions of New Zealand, Japan and California, but has not been tested in tectonically stable regions like Australia. We have made a preliminary test of the EEPAS procedure in Australia, beginning our analysis by applying it in a retrospective fitting mode to four regions of Australia, identified by Leonard (2005), that have relatively high levels of seismic activity and catalogue completeness. These include Southeast Australia, South Australia, Southwest Australia, and Northwest Australia. It appears from our preliminary analysis that the EEPAS procedure is applicable to the tectonically stable region of Australia. In Southeastern Australia, the data are sufficiently complete above M2.0 to use M2.0 as a minimum magnitude, with a target set of M>4.25 for the time period of 1975 – 2003. The optimal EEPAS parameters are similar to those obtained in tectonically active regions, except for a high value of 0.5 for the failure rate. The information gain per earthquake of EEPAS over a simpler model (PPE, i.e. Proximity to Past Earthquakes) is 0.64 for SE Australia, which is roughly the same as in other applications, but we note that this only a retrospective fitting exercise. We have tested the procedure in a prospective mode to the 1989 Newcastle earthquake. EEPAS did not indicate a large likelihood gain before the Newcastle earthquake, but the magnitude 5.3 Ellalong earthquake of 1994, together with the magnitude 5.5 Newcastle earthquake of 1989, give rise to increased probability of a larger earthquake in this region.

Introduction

At present, there is no generally recognised capability for earthquake prediction, which seismologists define as specifying the time of occurrence, location and size of an earthquake within reasonably narrow uncertainty bands. However, it has long been recognized that there are periodicities in earthquake occurrence, and recently it has become clear that earthquake forecasting based on the preceding sequence of earthquakes in a region is feasible. One kind of forecasting relates mainly to the occurrence of aftershocks in the very short term (hours and days) following a mainshock. Another kind of forecasting, which relates to the long term (years to decades) forecasting of mainshocks (which we define here as potentially damaging earthquakes), is based on decades of prior seismicity.

To date, the most successful long term earthquake forecasting method is the EEPAS procedure (Every Earthquake a Precursor According to Scale) developed by Evison and Rhoades (2004) and Rhoades and Evison (2004). These authors have shown that a mainshock is preceded by an increase in the rate of occurrence of smaller earthquakes in the surrounding region. These smaller earthquakes appear to herald the reloading of the region to a level of stress that locally exceeds the strength of the crust. Equations have been developed that relate the magnitude M of the impending earthquake to the duration of precursory seismicity and the size of the region in which it occurs. These equations provide the means to forecast the time-varying level of seismic activity throughout a region based on its preceding seismicity. This method does not predict specific earthquakes, but in hindsight specific earthquakes are found to have occurred in regions with high forecast levels of activity.

To date, the EEPAS procedure has been successfully tested in the tectonically active regions of New Zealand (Rhoades and Evison, 2004), California (Rhoades and Evison, 2004), Japan (Rhoades and Evison, 2005, 2006) and Greece (Console et al., in press). In this paper, we show that it is expected to be also effective in the tectonically stable region of Australia.

This development has important implications for the evaluation of seismic hazards. At present, seismic hazard analyses usually assume that earthquakes occur randomly in time (Poisson model). However, the accelerated seismicity model described above provides a much more accurate forecast of seismicity than the Poisson model. The use of a time-dependent method of analysis based on this model would potentially provide much more accurate estimates of earthquake loss in a given region during a given year. In a particular year, damaging earthquakes, if they occur at all, are likely to occur in locations that are identified as having an increased level of activity.

Analysis

We applied the EEPAS earthquake forecasting methodology in a retrospective fitting mode to the Southeastern Australia region. This is one of the four regions of Australia, identified by Leonard (2005), that have relatively high levels of seismic activity and catalogue completeness. The earthquake catalog that we have used is that described by Leonard (2005). In the Southeastern Australia zone, the seismicity data are sufficiently complete above M2.0 to use M2.0 as a minimum magnitude, with a target set of M>4.25 for the time period of 1975 – 2003. The optimal EEPAS parameters are found to be similar to those obtained in tectonically active regions, except for a high value of 0.5 for the failure rate. However, the uncertainty in the parameter estimates is large because of the small number of earthquakes (22) in the target set. The information gain per earthquake of EEPAS over a simpler model (PPE, i.e. Proximity to Past Earthquakes) is 0.64 for SE Australia, which is roughly the same as in other applications, but we note that this is only a retrospective fitting exercise.

Test against the 1989 Newcastle earthquake

We tested the EEPAS procedure against the 1989 Newcastle earthquake (McCue et al, 1990), because this is the largest earthquake to have occurred in Southeastern Australia in recent years. The magnitude of this earthquake in the catalog described by Leonard (2005), which we used for consistency, but note that McCue et al. (1990) prefer a magnitude of 5.6. The EEPAS precursory scale increase parameters for the 1989 Newcastle earthquake are shown in Figure 1. The epicenter of the earthquake is at about Latitude -33.0, Longitude 151.75. The average magnitude of the three largest precursory earthquakes MP is 3.5, the time interval over which the precursory activity occurred TP is 4144 days (over 11 years), and the area over which the precursory activity occurred AP is 518 km^2. Compared with many other examples of the precursory scale increase phenomenon (Evison and Rhoades, 2004), the Newcastle precursory increase of seismicity is typical, but TP is much longer than expected for an Mm 5.5 earthquake.

The EEPAS forecast is shown spatially in the form of rate density of earthquakes of a specified magnitude (Figure 2). The units shown in this figure are RTR units, which is a comparison with a reference density in which there is an expectation of 1 earthquake per year exceeding any magnitude M in an area of 10m km^2. With this normalization, the average rate density in a region in RTR units is approximately constant over all magnitudes. In more seismically active plate boundary regions such as New Zealand and California, the average RTR value is about 1. In SE Australia the average RTR value is about 0.015.

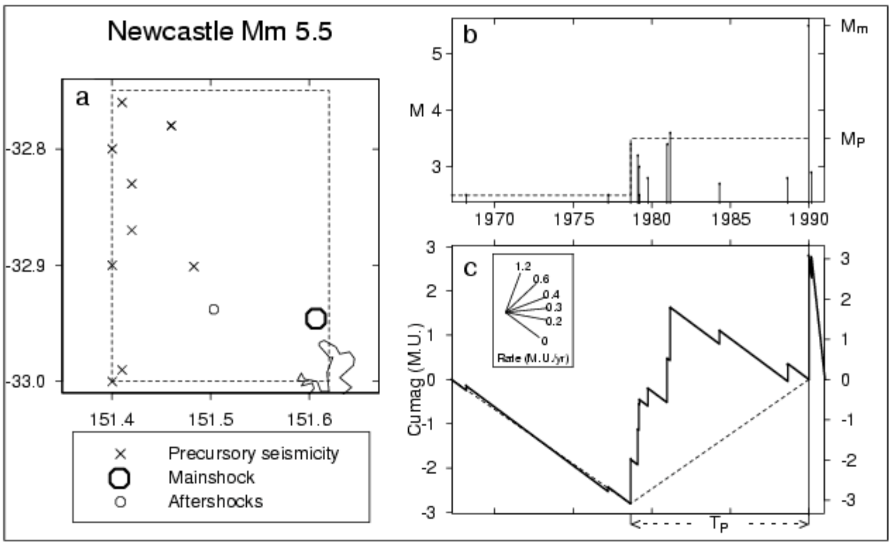

Figure 1. Precursory scale increase for Newcastle Mm 5.5 earthquake of 1989/12/27. MP = 3.5, TP = 4144 days, AP = 518 km^2. (a) Epicentres of precursory earthquakes, mainshock and aftershocks. Dashed lines enclose the precursory area AP. (b) Magnitudes versus time of prior and precursory earthquakes, also mainshock and aftershocks. Dashed lines show precursory increase in magnitude level. Mm is mainshock magnitude; MP is precursor magnitude. (c) Cumulative magnitude anomaly (Cumag) versus time. Dashed lines show precursory increase in seismicity rate. Protractor translates cumag slope into seismicity rate in magnitude units per year (M.U./yr), for times before the mainshock. Cumag values at the right hand ordinate refer to times beginning with the mainshock.

Figure 2 shows the earthquake forecast in Southeastern Australia just before the 1989 Newcastle earthquake. The RTR in the epicentral region of Boolaroo just west of Newcastle has a value of about 0.05 (yellow colour in Figure 2). Thus the EEPAS procedure indicated a moderate likelihood gain before the Newcastle earthquake.

The M5.3 Ellalong earthquake of 1994, together with the M5.5 Newcastle earthquake of 1989, have since given rise to increased probability of a larger earthquake in this region, as shown in Figures 3 through 6. The likelihood as of 2004/1/1 of an M5.5 earthquake has not changed, as shown in Figure 3, and becomes larger in relative terms (compared with other locations) for increasingly large earthquakes, as shown for M7 in Figure 4. Although the absolute likelihood of an earthquake in a given region of fixed area does not increase with magnitude, the RTR values in the Newcastle area increase up to M7 because the probability increase is centered on magnitudes 1 - 2 units higher than those of the earthquakes generating it (i.e., 5.5 and 5.3). The increased probability at around M7 would have arisen gradually over the preceding decade and will subside gradually over the next 1 – 2 decades, unless reinforced by the occurrence of further earthquakes of magnitude 5 – 6 in the same vicinity.

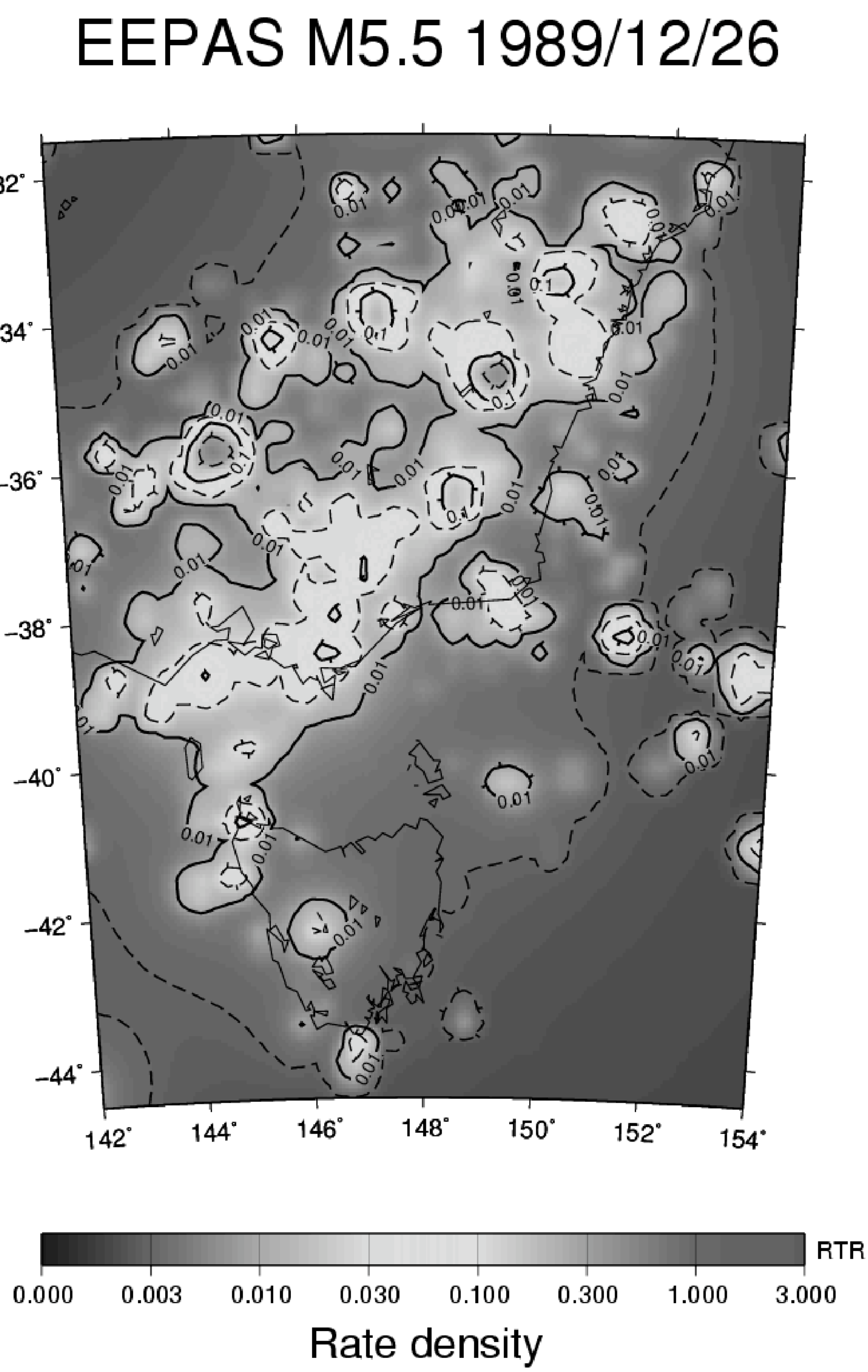

Figure 2. EEPAS rate density of earthquake occurrence in Southeastern Australia as at 1989 Dec 26, just before the Newcastle earthquake for M5.5 in RTR units, i.e. relative to a reference density in which there is an expectation of 1 earthquake per year exceeding any magnitude m in an area of 10m km^2. Seismicity data to 26 December 1989.

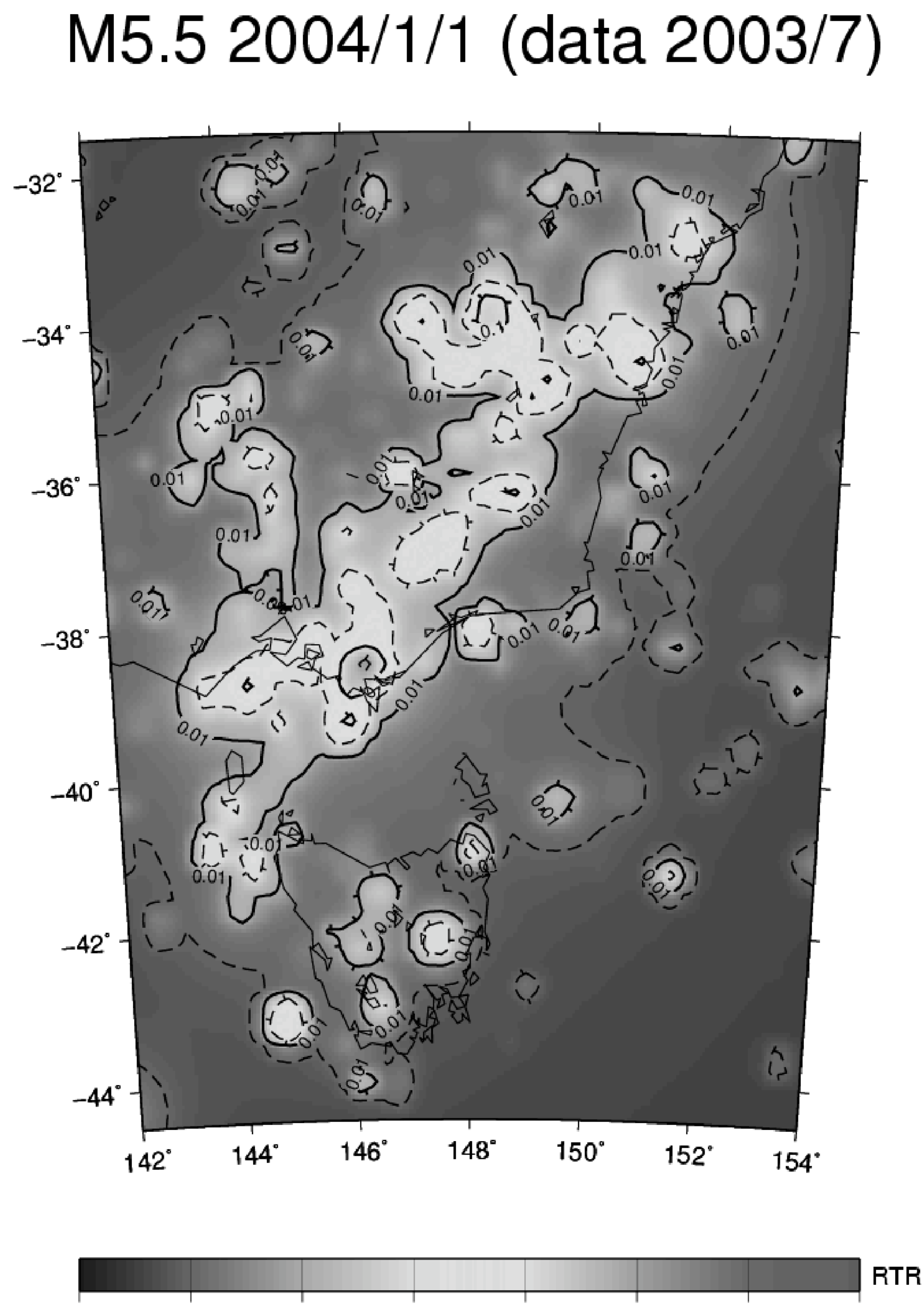

Figure 3. EEPAS rate density of earthquake occurrence in Southeastern Australia as at 2004 Jan 1 for M5.5 in RTR units, i.e. relative to a reference density in which there is an expectation of 1 earthquake per year exceeding any magnitude m in an area of 10m km^2. Data to July 2003.

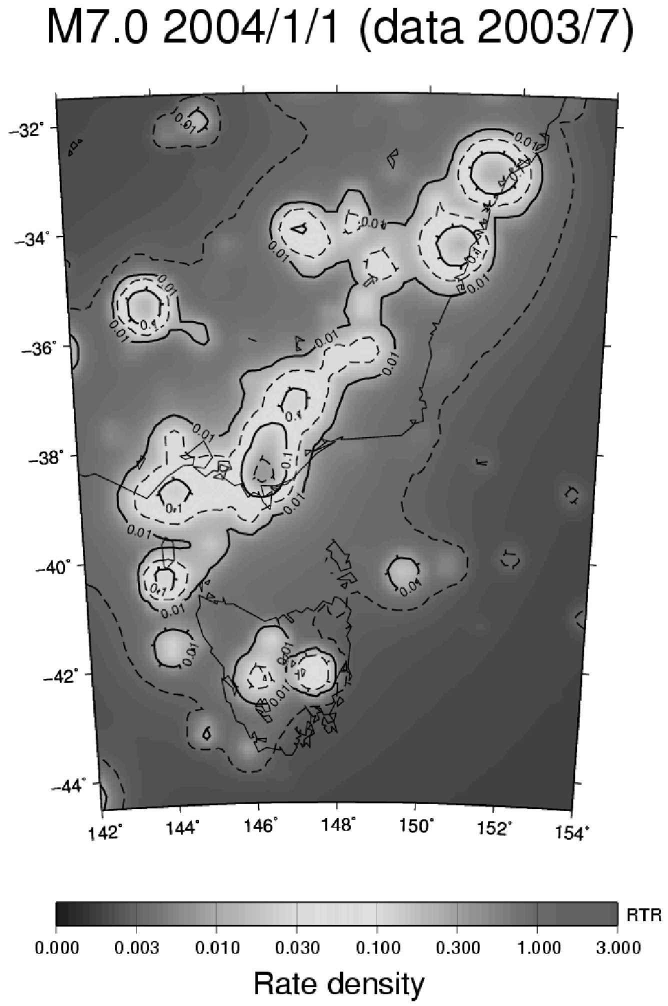

Figure 4. EEPAS rate density of earthquake occurrence in Southeastern Australia as at 2004 Jan 1 for M7.0 in RTR units, i.e. relative to a reference density in which there is an expectation of 1 earthquake per year exceeding any magnitude m in an area of 10m km^2. Data to July 2003.

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