How frequent are earthquakes?

A question always asked by members of the public (and reporters) to seismologists is can you predict earthquakes, and if you cannot then what is the point of seismology.   Once you have a basic understanding of plate tectonics and the fundamental causes for earthquakes it becomes obvious that they are not random events but rather the logical end product of a long series of movements and stresses building up in the Earth at specific points.   They should be predictable.   However despite an enormous amount of money being spent on researching the problem and the dubious claims of some scientists there is as yet no successful method for predicting the exact timing and magnitude of earthquakes.

In essence the Earth is too complex a system for us to successfully model its behaviour to such a fine detail, in fact some scientists think that it is a fundamentally unsolvable problem. Before an earthquake, the stresses on a faults system can remain critically balanced for some considerable time. Knowing when the fault will slip (i.e. an earthquake will happen) depends on so many additional factors (some microscopic in nature) in addition to the stress that it becomes unpredictable.

An analogy is with predicting the behaviour of sand in an egg timer.   We can predict with great accuracy how long the sand will take to fall through to the lower chamber.   We can predict what shape the pile of sand will make in the lower chamber.   However we cannot predict where an individual grain of sand will end up when it falls through the hole.

Although predicting the exact timing of an earthquake is too difficult for scientists at present it is possible to calculate some statistics about the likelihood of an earthquake striking at a particular location.   This then enables engineers to design buildings to withstand the likely ground shaking for a particular area (and they will use more stringent rules for designing a hospital or a nuclear power station than a warehouse).

A simple seismometer installed in a school in the UK should detect signals from any earthquake in the world greater than magnitude 7.0 and should detect any global event greater than magnitude 6.5 if it occurs at night time (when there are fewer road traffic vibrations and vibrations in the school caused by pupils).   If we are going to conduct an experiment designed to record vibrations from an earthquake we ought to know how long the experiment will last.   How long would you have to wait before you record an earthquake?
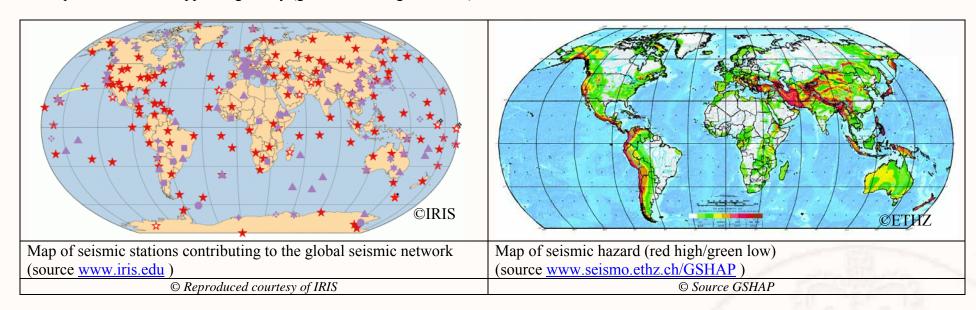

© Reproduced courtesy of Martin Olsson under GNU FDL http://en.wikipedia.org/wiki/Wikipedia:Text_of_the_GNU_Free_Documentation_License

NATURAL ENVIRONMENT RESEARCH COUNCIL

Global monitoring

Scientists have been monitoring earthquakes with a worldwide network of standardised seismometers since the 1970s and accurate records of all earthquakes that have happened globally (greater than magnitude 5.0) since 1990 are available online.

©IRIS

©ETHZ

Map of seismic stations contributing to the global seismic network (source www.iris.edu)	Map of seismic hazard (red high/green low) (source www.seismo.ethz.ch/GSHAP)
© Reproduced courtesy of IRIS	© Source GSHAP

Seismic hazard is usually calculated as a peak ground acceleration (in units of m/s^2) with a 10% probability of being exceeded within a 50 year period. This information about the likely intensity of shaking is what structural engineers need in order to calculate how strong buildings within a particular area need to be. The UK generally has a value of less than 0.4 m/s^2 whereas parts of Greece and Turkey have values as high as 5 m/s^2. Building regulations are far stricter in areas of greatest seismic hazard.

NATURAL ENVIRONMENT RESEARCH COUNCIL

Simple probability

A simple observation is that worldwide on average there are 18 earthquakes each year of magnitude greater than 7.0.   So the average recurrence time for these earthquakes should be 365/18 or about 20 days.   However this does not mean that major earthquakes happen every 20 days, a more meaningful calculation would be to calculate the probability of a major earthquake occurring.

Descriptor	Magnitude	Average annually
Great	8 and higher	1
Major	7–7.9	17
Strong	6–6.9	134
Moderate	5–5.9	1319
Light	4–4.9	13,000 (estimated)
Minor	3–3.9	130,000 (estimated)
Very minor	2–2.9	1,300,000 (estimated)
Frequency of occurrence of earthquakes globally (from USGS)		

If we assume that globally the timing of earthquakes is random and earthquake events are independent then we can say that the chance of such an event happening today is 18/365 or 0.05   i.e. there is a 5% chance of a major earthquake occurring today. (Note this simple approach only works if the probability of two earthquakes happening on the same day is very small.   For other situations you have to consider the probability distribution of events.)

You can download lists of earthquakes from a number of internet sources. One of the easiest to use is the hosted by the United States Geological Survey (USGS)
http:/ neic.usgs.gov/neis/eqlists/eqstats.html /

To calculate how long we would have to wait before a >M7.0 event it is easier to consider the probability of such an event not occurring, which is 347/365 or about 0.95. i.e. there is a 95% chance of a major earthquake not occurring today. Using the multiplication rule for probabilities we can calculate that the probability of an event not happening for two consecutive days is 0.95*0.95 =0.9025.   i.e. the chance of a major earthquake not occurring for two days on the run drops to about 90%.

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Prob.	0.95	0.90	0.86	0.81	0.77	0.74	0.70	0.66	0.63	0.60	0.57	0.54	0.51	0.49

If we tabulate the probability of an event not occurring with increasing time we find that to reach a 50% probability of a >M7.0 event not occurring (and hence a 50% probability of an event occurring) we need to wait for 14 days. For a 90% probability of detecting a >M7.0 event we would have to wait 45 days though. (For 100% probability we would have to wait for ever!)

Probability using a Poisson distribution (advanced)

A more accurate approach would be to assume that the distribution of global earthquakes follows a Poisson distribution.   This distribution was discovered by the French scientist Siméon-Denis Poisson in 1837 and it allows the calculation of the probability of a number of events occurring in a fixed period of time if they occur with a known average rate and are independent of the time since the previous event. It is used widely throughout science and engineering.

If we assume that the probability P of *n* earthquakes during a time interval *t* is given by

$$P(n,t,\tau) = (t/\tau)^n e^{-t/\tau} / n!$$

Where τ is the average recurrence time for the event.

Then the probability that no events will occur in a time interval t is given by

$$P(0,t,\tau) = e^{-t/\tau}$$

Or the probability that at least one event will occur is

$$P(n \geq 1, t, \tau) = 1 - e^{-t/\tau}$$

Using a Poisson distribution for events greater than M7 and an average recurrence time of 20 days then we reach a 50% probability of there being an event in 14 days and 90% probability in 46 days

This is a slightly more accurate method of calculating the probability of an event, however it does rely on earthquake events not being related to each other.

Table of probabilities for simple vs poisson distributions

| Days	Simple	Poisson	Days	Simple	Poisson
1	0.050	0.049	26	0.736	0.727
2	0.098	0.095	27	0.750	0.741
3	0.143	0.139	28	0.762	0.753
4	0.185	0.181	29	0.774	0.765
5	0.226	0.221	30	0.785	0.777
6	0.265	0.259	31	0.796	0.788
7	0.302	0.295	32	0.806	0.798
8	0.337	0.330	33	0.816	0.808
9	0.370	0.362	34	0.825	0.817
10	0.401	0.393	35	0.834	0.826
11	0.431	0.423	36	0.842	0.835
12	0.460	0.451	37	0.850	0.843
13	0.487	0.478	38	0.858	0.850
14	0.512	0.503	39	0.865	0.858
15	0.537	0.528	40	0.871	0.865
16	0.560	0.551	41	0.878	0.871
17	0.582	0.573	42	0.884	0.878
18	0.603	0.593	43	0.890	0.884
19	0.623	0.613	44	0.895	0.889
20	0.642	0.632	45	0.901	0.895
21	0.659	0.650	46	0.906	0.900
22	0.676	0.667	47	0.910	0.905
23	0.693	0.683	48	0.915	0.909
24	0.708	0.699	49	0.919	0.914
25	0.723	0.713	50	0.923	0.918

NATURAL
ENVIRONMENT
RESEARCH COUNCIL
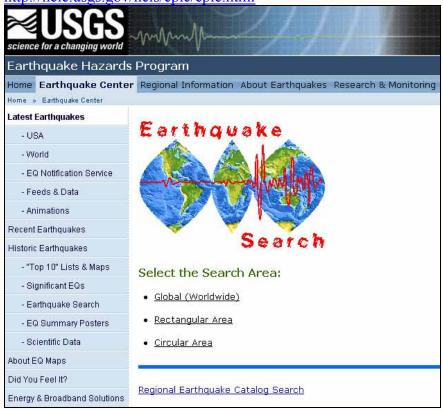
Internet search activity

Use the USGS earthquake search facility to discover more details about the frequency of earthquakes of different magnitudes and in different areas.

http://neic.usgs.gov/neis/epic/epic.html

© *Reproduced courtesy of USGS*

Some suggested searches

Calculate the average recurrence time for:

Earthquakes >M7.0 in different 2 year periods

Earthquakes >M6.5 in different 2 year periods

Earthquakes>M7.0 in a hemisphere (9990 km radius) centred on lat 0 N lon 30 E
Earthquakes>M7.0 in a hemisphere (9990 km radius) centred on lat 0 N lon 150 W

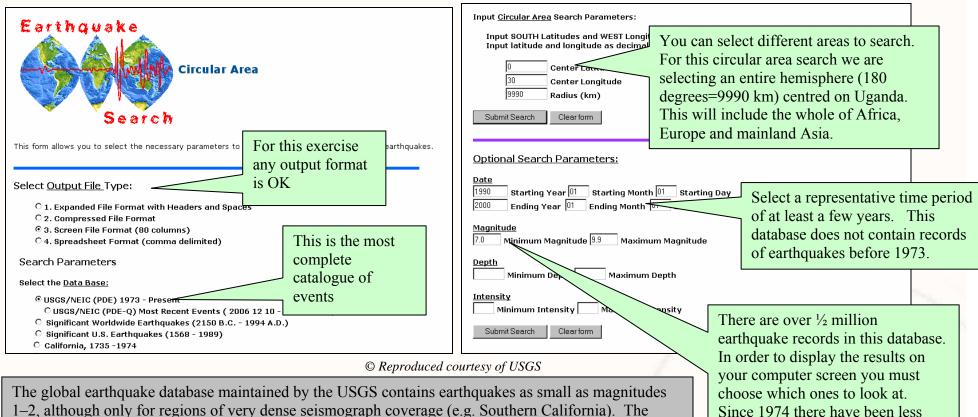Earthquakes >M6.0 within 2000 km of lat 3 N lon 96 E
Dec 1–25 2004
Earthquakes >M6.0 within 2000 km of lat 3 N lon 96 E
Dec 26 2004–Jan 19 2005

You can select either a global search or search a rectangular or circular area.

© *Reproduced courtesy of USGS*

Earthquake · **Circular Area** · **Search**

This form allows you to select the necessary parameters to ...... earthquakes.

Select Output File Type:

- ○ 1. Expanded File Format with Headers and Spaces
- ○ 2. Compressed File Format
- ◉ 3. Screen File Format (80 columns)
- ○ 4. Spreadsheet Format (comma delimited)

Search Parameters

Select the Data Base:

- ◉ USGS/NEIC (PDE) 1973 - Present
- ○ USGS/NEIC (PDE-Q) Most Recent Events (2006 12 10 - ...
- ○ Significant Worldwide Earthquakes (2150 B.C. - 1994 A.D.)
- ○ Significant U.S. Earthquakes (1568 - 1989)
- ○ California, 1735 -1974

Input Circular Area Search Parameters:

Input SOUTH Latitudes and WEST Longi...
Input latitude and longitude as decimal...

0	Center Lat...
30	Center Longitude
9990	Radius (km)

Submit Search   Clear form

Optional Search Parameters:

Date

| 1990 | Starting Year | 01 | Starting Month | 01 | Starting Day |
| 2000 | Ending Year | 01 | Ending Month |

Magnitude

| 7.0 | Minimum Magnitude | 9.9 | Maximum Magnitude |

Depth

| | Minimum Dep... | | Maximum Depth |

Intensity

| | Minimum Intensity | | Ma... ...nsity |

Submit Search   Clear form

> For this exercise any output format is OK

> This is the most complete catalogue of events

> You can select different areas to search. For this circular area search we are selecting an entire hemisphere (180 degrees=9990 km) centred on Uganda. This will include the whole of Africa, Europe and mainland Asia.

> Select a representative time period of at least a few years. This database does not contain records of earthquakes before 1973.

> There are over ½ million earthquake records in this database. In order to display the results on your computer screen you must choose which ones to look at. Since 1974 there have been less than 500 earthquakes larger than magnitude 7.0

The global earthquake database maintained by the USGS contains earthquakes as small as magnitudes 1–2, although only for regions of very dense seismograph coverage (e.g. Southern California). The completeness of the catalogue depends on the minimum magnitude event that could occur anywhere and still be detected. Since the majority of seismograph stations are located on land this means that mid-ocean events (usually on tectonic spreading centres) which might be thousands of kilometres from the nearest seismograph stations (and remember we need at least 3–4 stations to determine an event location and time) limit the catalogue completeness. The USGS catalogue is complete for earthquakes of magnitude greater than 5.1
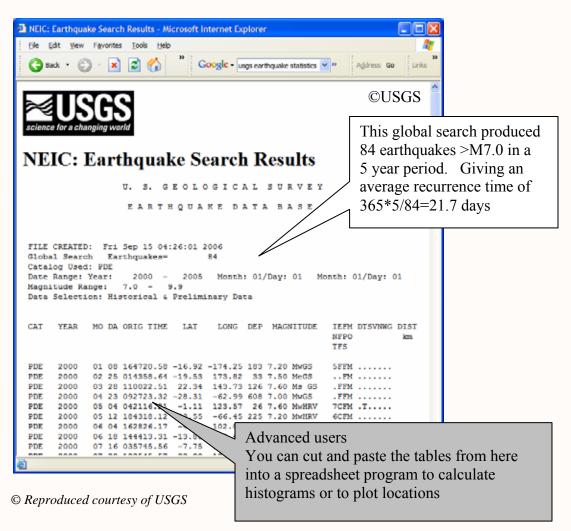
British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

You should get back a list of events. To calculate probabilities and average recurrence rates you just need to know to total number of earthquakes that your search produced

©USGS

This global search produced 84 earthquakes >M7.0 in a 5 year period. Giving an average recurrence time of 365*5/84=21.7 days

Advanced users
You can cut and paste the tables from here into a spreadsheet program to calculate histograms or to plot locations

© Reproduced courtesy of USGS

How frequent are earthquakes   7   Author Paul Denton

NATURAL ENVIRONMENT RESEARCH COUNCIL

Complications
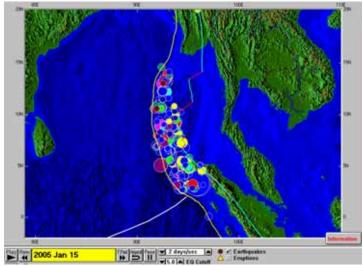
In practice the timing of earthquakes is far more complex than this.

Seismologists noticed a regular pattern to earthquakes at Parkfield in California with an apparent 20 year cycle. They predicted with 95% probability that an earthquake M5–6 would occur near Parkfield in the period 1985–1993. There was a magnitude 5.9 event in 2004, over 10 years 'late'.

Intuitively you would expect there to be less probability of a large earthquake happening immediately following an initial large event. A simple elastic rebound model suggests that time is required for stress levels to build up to a critical level before an earthquake can be triggered. However there are usually a large number of smaller earthquakes on the same fault zone immediately following a large event, the frequency of these aftershocks decays with time.

In the 5 days after the M9.3 event in Sumatra on Boxing Day 2004, there were 17 events >M6.0 in the same region. Globally the average recurrence time for events >M6.0 is about 2 days.

Sometimes smaller earthquakes appear in swarms often associated with volcanic activity or sometimes with no apparent reason. In October –November 2002 a swarm of over 100 small (<M3.9) earthquakes occurred in Manchester, no-one knows why these earthquakes happened there at that time.

© Reproduced courtesy of Alan Jones

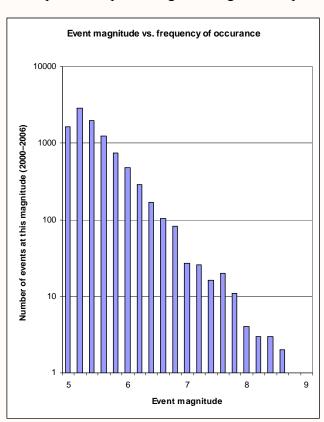Aftershocks of the M9.3 Boxing Day 2004 event in Sumatra define the slip area of the original earthquake

NATURAL ENVIRONMENT RESEARCH COUNCIL

Gutenberg-Richter relationship (advanced)

If we plot earthquake magnitude against frequency of occurrence we see an interesting pattern.
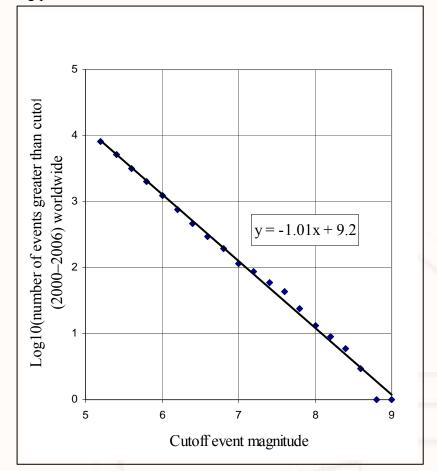

Event magnitude vs. frequency of occurance

Plotting the number of earthquakes against magnitude seems to show a linear relationship between the Log10 of the number of events and the magnitude. –1

If we reformulate this as a cumulative plot, the number of earthquakes per year of magnitude M or greater, N(M) is given by

$$LogN(M) = a - bM$$

where b~1. A '**b**' value of 1.0 means that there are 10 times as many earthquakes >M5.0 as there are >M6.0 and 100 times as many earthquakes >M4.0 as >6.0.

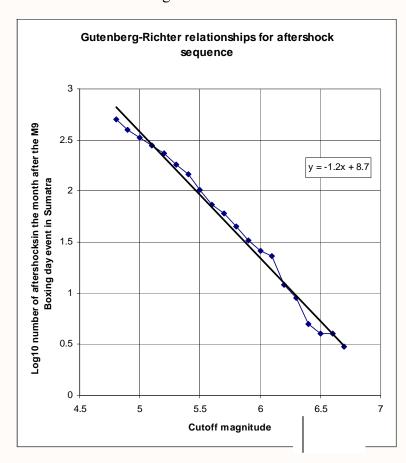
$y = -1.01x + 9.2$

NATURAL
ENVIRONMENT
RESEARCH COUNCIL

This relationship seems to hold true for earthquakes globally with a b value of about 1. This b value will vary a little when you consider subsets of events from different regions but is remarkably consistent. Although the 'b' value on this plot (The 'slope' of the line) is generally constant the intercept value will vary greatly for different regions.

This means that although earthquakes >M5.0 are 10 times less frequent than earthquakes >M4.0 in both the UK and California the frequency of these events is much higher in California

Gutenberg-Richter relationships for aftershock sequence

$y = -1.2x + 8.7$

Log10 number of aftershocks in the month after the M9 Boxing day event in Sumatra

Cutoff magnitude

Aftershocks

However when you look at catalogues of aftershocks (i.e. events that occur shortly after a large event that are caused by the change in stress regime brought about by a large event) you find this relationship changes to one where smaller events are more frequent (i.e. a higher 'b' value.) Other variations in 'b' value between regions are also thought to relate to differences in crustal stress. But be careful – 'b' values can't be determined reliably for samples of less than about 100 earthquakes.

Suggested activity

Using the USGS earthquake catalogue search facility:

Try and find out the scaling laws for different areas (e.g. a high seismicity area and a medium seismicity area)

NATURAL
ENVIRONMENT
RESEARCH COUNCIL