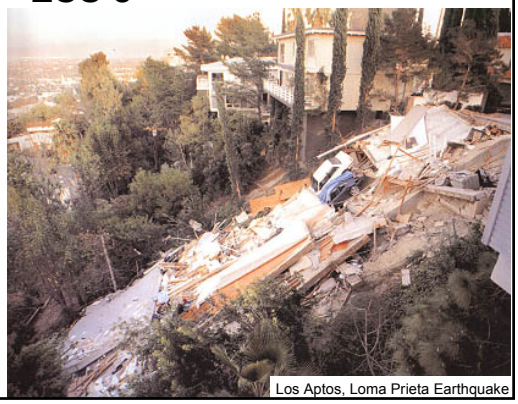
ESS 8



Los Aptos, Loma Prieta Earthquake

Last Time

- Number of earthquakes
  - Gutenberg-Richter
  - Smallest earthquake?
- Mainshocks, foreshocks and aftershocks
  - Aftershock locations
  - Omori's Law
- Non-conventional sequences
  - Swarms, long-range triggering, jumping faults

Today and Next Time

- Earthquake prediction
  - Post-dictions and precursors
  - Forward predictions
    - Deterministic (or nearly) short-term
    - Probablistic long-term
- Reading: Chapt. 5

To make an earthquake prediction need to state:

- Time interval in which quake will occur
- Region in which quake will occur
- Magnitude range of predicted quake
  - Small quakes occur more commonly
  - Easy to predict there will be magnitude 3 somewhere in Southern Ca. next month, but not useful

Describing magnitude

- Under M 5
  - Small
- M 5 to 6
  - Moderate
- M 6 to 7
  - Large
- M 7 to 7.8
  - Major

M 7.8 or above

Great

ODDS OF SEISMICITY FOR NORTHERN AND CENTRAL CALIFORNIA

Box 10.3

The *Bulletin* of the Seismographic Stations of the University of California lists 3638 earthquakes ($3.0 \leq M_L \leq 6.9$), which occurred in the 280,000 square kilometer area of northern and central California from 1949 through 1983. The cumulative number of earthquakes (N) expected with an assigned magnitude M_L is

$$\log N = 4.23 - 0.815\, M_L ,$$

normalized to earthquakes per year per 280,000 square kilometers.

The annual rate of seismicity ($r = 10^{\log N}$) in earthquake sequences per year and the percent probability of one or more earthquakes of magnitude M_L or larger occurring in one day, week, month, year, or decade is:

		Percent probability in one				
$M_L \geq$	r (eq/yr)	day	week	month	year	decade
3.0	60.0	15.0	69.0	99.0	100.0	100.0
3.5	24.0	6.3	36.0	86.0	100.0	100.0
4.0	9.2	2.5	16.0	54.0	100.0	100.0
4.5	3.6	0.99	6.7	26.0	97.0	100.0
5.0	1.4	0.39	2.7	11.0	76.0	100.0
5.5	0.55	0.15	1.1	4.5	43.0	100.0
6.0	0.22	0.059	0.42	1.8	19.0	89.0
6.5	0.085	0.023	0.16	0.71	8.1	57.0
7.0	0.033	0.009	0.064	0.28	3.3	28.0

ca. 1610-15; Bartolomeo Manfredi

It is easy to predict an earthquake.

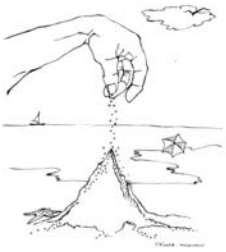
There will be a magnitude 3 in California next month.

Not too useful.

Impossible?

- Perhaps there is no information about exact time, place and size

Sandpiles and Critical States



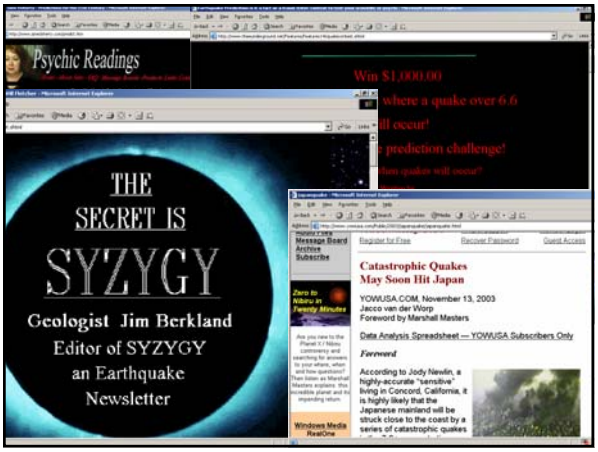
Adding a grain of sand to a steep sandpile can cause any size earthquake

If the Earth is always in a critical state, there is no way to predict if the next earthquake will be small or large

Fakes

- Richter in 1977:

"Journalists and the general public rush to any suggestion of earthquake prediction like hogs toward a full trough... [Prediction] provides a happy hunting ground for amateurs, cranks, and outright publicity-seeking fakers"



Myths to debunk

- Earthquake weather
- My dog barked at a strange pitch (or cat ran in circles or horse jumped through the fence, etc.)
- Big earthquakes always happen in the early morning

Optimism

- Some success
  - Haicheng 1975
- Many possible phenomena to study

Two strategies

- Find a specific precursor
  - Water level changes, electromagnetic waves, foreshocks, etc.
- Forecast a general pattern
  - Earthquakes are more likely when there are many earthquakes
  - 62% probability of at least one magnitude 6.7 in the San Francisco Bay region before 2032.

Possible precursors

- Change (increase or decrease) in number of earthquakes
  - For example, foreshocks
- Slow ground motion (geodetically measured)
- Radon emission
- Electrical resistivity
- Electromagnetic waves
- Water chemistry
- Seismic wave velocity

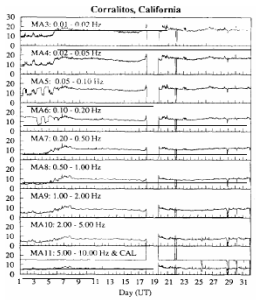
Post-dictions

- Retrospective predictions
  - After an earthquake happens, look for strange signals before it
- VERY dangerous practice
  - There is always something strange happening
- However, might be the only way to learn
  - Seismology is an observational science

Example 1: Electromagnetic fluctuations

- Oct. 17, 1989 Loma Prieta Earthquake
- Measurements 7 km from epicenter
- Increase in signal
- Oct. 5 and again Oct. 17

Never found for another earthquake

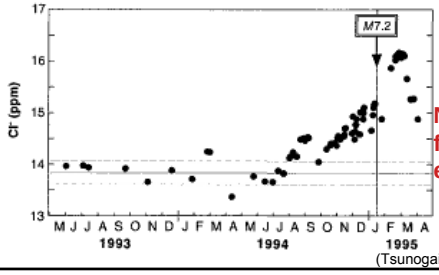


Example 2: The bottled water story

Jan. 17, 1995
Kobe
Earthquake

Chemical precursor

• Analyzed dated, bottled water
• Found ~6 month precursor in chloride and other chemicals



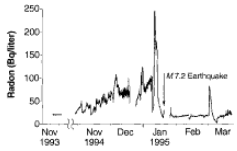
Never found for another earthquake

(Tsunogai and Wakita, 1995)

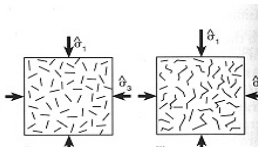
Radon

- Radon is a radioactive gas emitted by rocks
- Radon gas concentration also increased before Kobe (Igarashi et al., 1995)
- A few days-long signal

Found for a few earthquakes

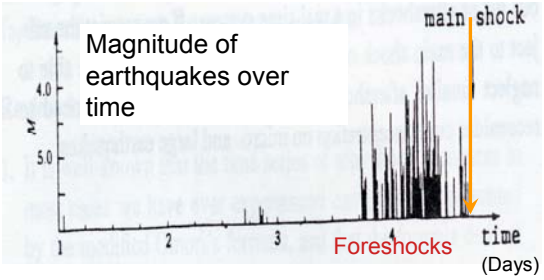


Radon expected?



- Increasing stress increases very small fractures in rocks before earthquake
- Releases small quantities of gas from rock
- The more fractures, the more gas released.

Forward Prediction: Ex #1 Haicheng 1975



Clustering of seismicity

- Whenever there is a quake, it becomes more likely that more quakes will come soon
- 10% chance that any quake will be followed by a bigger quake
- With passing time (and no quake), odds return to normal

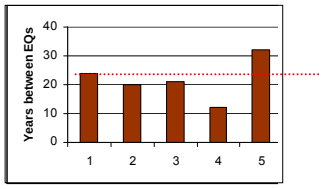
Forward Prediction #2: Parkfield

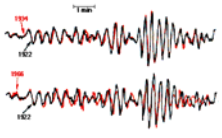
M 6 earthquake before 1857 M8+ earthquake

USGS

Hypothesis:

- **Parkfield M6** EQ has 22 year repeat time (no precursor)
- Always ruptures the same segment (the same direction?)





- Broke in 1857, 1881, 1901, 1922, 1934, 1966, ?
- FINALLY… Sept. 2004

Is the pattern real?

- Maybe historical data is bad
  - Intensity in central California sparse in the 19th century
- Maybe data is good, but random
  - Not hard to find spurious patterns
  - Like presidential deaths in office

American Presidents

- 1861-1865: A. Lincoln (elected 1860)
  - 1865 April 14, Wounded by assassin John Wilkes Booth; 1865 April 15, died early in the morning from wound in Washington, D.C.
- 1881-1884: J. Garfield (elected 1880)
  - 1881 July 2, Wounded by assassin in Washington, D.C., 1881 September 19, died from wounds at Elberon, New Jersey
- 1897-1901: W. McKinley (re-elected 1900)
  - 1901 September 6, Shot by an assassin in Buffalo, New York, September 14, died from wounds in Buffalo
- 1921-1924 W.G. Harding (elected 1920)
  - 1923 August 2, died in San Francisco
- 1933-1945 F.D. Roosevelt (re-elected 1940)
  - 1945 April 12, died at Warm Springs, Georgia
- 1961-1964: J.F. Kennedy (elected 1960)
  - 1963 November 22, Assassinated in Dallas, Texas
- 1981-1984: R. Reagan (elected 1980)
  - 1981 March 30, wounded in an attempted assassination
- 2001-2005 GW Bush? (elected 2000)

Problems with false alarms

- Disruptive
- Expensive
- Make people less likely to respond next time
  - "Cry Wolf"

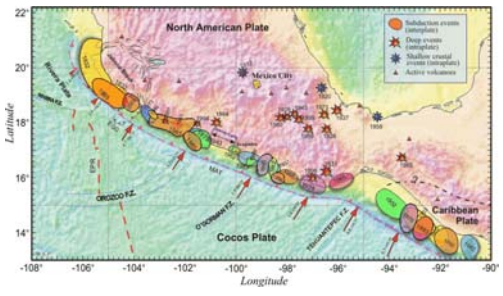
China discouraging predictions

- From journal *Nature*, January 28th, 1999
- Unofficial earthquake warnings
  - 30 in the last 3 years
  - Brought factories and business to a halt
  - None has been accurate
- New law
  - Requires high standard of scientific reasoning
  - Or else predictors will be penalized

Quiescence

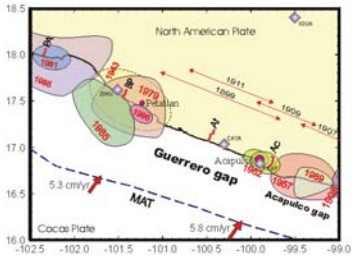
- Earthquakes are due if they have not happened in a while
  - Are we due for a big one?
- Seismic gaps

Forward Prediction #3: Mexican coast

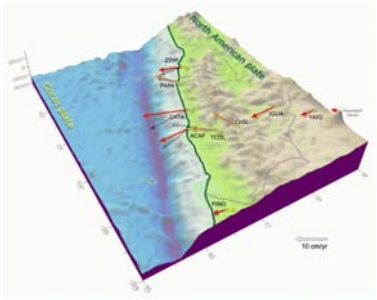


http://tlacaelel.igeofcu.unam.mx/~vladimir/sismos/100years.html

Guerrero gap



Slow Slip event

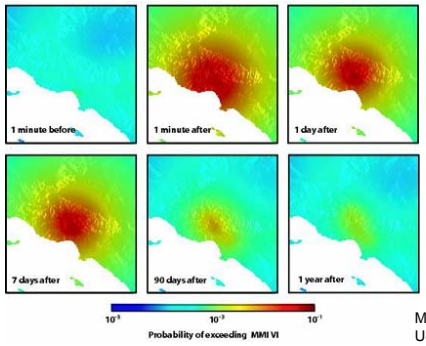


http://tlacaelel.igeofcu.unam.mx/~vladimir/guerrero_level/deform0.html

Probabilistic Prediction

- Deterministic Prediction = Specific statements about when, where and how big
  - Often short-term (weeks- month)
- Probablistic Prediction
  - Short-term (Gutenberg-Richter & Omori's)
  - Long-term Forecasts
    - Forecast
    - Based on long-term data

Short-Term Probabilistic Prediction



After Northridge (Post-diction)

M. Gerstenberger USGS

Forecast: 2002 Working Group Bay area report

- Calculated 62% probability of a major (≥6.7) earthquake n the Bay Area in the next 30 years

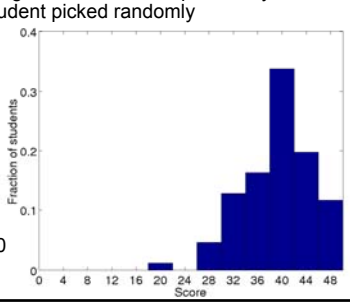
Image courtesy USGS

Probability

- How often you expect something to happen
  - ex) Flipping a coin lands on heads 50% of the time
- Reported as percent (50%), decimal (0.5) or fraction (1/2)
- Must be between 0% and 100%

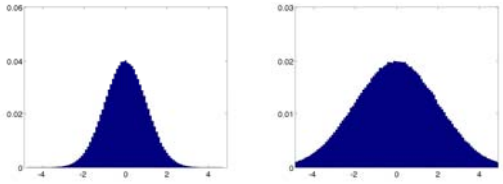
Bell curves: Exam Results

- Distribution of student grades determines probability of a certain grade for a student picked randomly
- Most probable result: between 38 and 42 correct (34% of students)
- 66% of students between 35 and 45
  95% between 30 and 50



Probability distributions

- Probabilities form curve



- Probabilistic predictions reports most probable (like the mean of exam) and measure of error (width of the peak)

Confidence Interval

- Confidence interval measures the probability that a probability is correct
- Ex) Bay area group reports 62% probability of a major earthquake with a 95% confidence interval between 37% and 87%
- 95% confidence interval says that 95% of the time, the probability will be between the bounds
  - Lots of error
  - Still useful for insurance companies, government planners, etc.

Ingredients for Short-Term Probablistic Predictions (Input)

- Statistical observations
  - Gutenberg-Richter
  - Omori's Law
- Current state of seismicity
- Mechanics (we wish…)

Ingredients for Long-term forecasting (Input)

- Past history
- Fault map
- Current activity
- Geodesy and other geophysical indicators
- Mechanics

Past History

"The past is key to the present"

- Instrumental records
- Historical records
- Geological records

California Records

- Instrumental
  - Early twentieth century
- Historical
  - Late 1700's (missions)
- Geological
  - ~600 A.D.

Recurrence intervals

- Recurrence interval is the time between similar earthquakes
- Typically hundreds of years for major earthquakes
  - Less for smaller (Gutenberg-Richter)
  - Therefore instrumental record is useless and the historical one is nearly so.

Paleoseismology

- Paleoseismology: The study of geological indicators of ancient earthquakes

Today

- Definition of prediction
  - where, when and how big
  - Classification of size of earthquakes
- Prediction myths
  - Earthquake weather, animals, mornings
- Precursors and post-dictions
  - Water chemistry, magnetic fields and radon
- Forward prediction
  - Parkfield, Foreshocks and seismic gaps
- Probability
  - confidence intervals
- Recurrence Inteverals