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Operational Earthquake Forecasting At the USGS

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Operational Earthquake Forecasting At the USGS

USGS Role: The USGS has a responsibility to undertake OEF due to the Disaster Relief Act of 1974 (P.L. 92–288). Popularly known as the Stafford Act, this law gives the USGS the Federal responsibility to issue warnings for earthquakes, volcanic eruptions, and landslides, so as to enhance public safety and to reduce losses through effective forecasts and alerts.

USGS Director is advised by the National Earthquake Prediction Evaluation Council.

Close coordination with the California Earthquake Prediction Evaluation Council.

NEPEC has endorsed the USGS OEF Strategy which includes testing through CSEP.

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What is the Basis for Operational Earthquake Forecasting at the USGS?

Currently OEF = Earthquake Clustering
a.k.a. Foreshocks and Aftershocks

Earthquakes trigger other earthquakes.

When you have one earthquake,
the probabilities for other earthquakes go up.

Practiced in one form or another since the mid-1980s: Parkfield, STEP, California Advisory Plan, Routine Aftershock Messages, Special Statements after Haiti, Mineral Springs, Myanmar.

Viewed as so obvious we can't avoid it.

What Is the Structure of Operational Earthquake Forecasting at the USGS?

Research – Research on earthquake processes, develop algorithms

Model Development – Make the algorithms testable and usable, possibly including real-time data

Model Testing – Test submitted algorithms to determine what does the best job

Message Design – determine what products would best convey useful information, develop explanatory material

Production – Input real time data to tested algorithm and produce products

Assessment – determine if the products communicate as desired

What Is the Structure of Operational Earthquake Forecasting at the USGS?

Research –

Model Development –

Model Testing –

Message Design –

Production –

Assessment –

The Route In For New Methods: Transient Deformation, Seismicity Patterns, Tremor, Electromagnetics….

What Is the Structure of Operational Earthquake Forecasting at the USGS?

Research –

Model Development – The Route In For New Methods: Transient Deformation, Seismicity Patterns, Tremor, Electromagnetics….

Model Testing –

Message Design – Rename OEF

Production –

Assessment –

The Questions

1. Describe a typical forecast:
    a. What area do they cover?
    b. What is the magnitude range?
    c. How long is the time period?
    d. Do you include a probability of an event during the forecast?
    e. Do you include a confidence level in the forecast?

2. Describe the process for making a forecast:
    a. Is it automatic or manual?
    b. What data are used?

3. Do you have a preference for which earthquake data should be used to test your forecasts?

4. Do you have a preferred testing method?

5. What physical hypotheses about earthquake predictability have motivated your research?

The Questions

1. Describe a typical forecast:
   a. What area do they cover?
   b. What is the magnitude range?
   c. How long is the time period?
   d. Do you include a probability of an event during the forecast? Probability or Expected Number
   e. Do you include a confidence level in the forecast? No, but we could give a range of values.

2. Describe the process for making a forecast:
   a. Is it automatic or manual? Currently manual, working on automatic.
   b. What data are used? Observed earthquakes.

3. Do you have a preference for which earthquake data should be used to test your forecasts? Epicenters and magnitudes from ANSS catalog.

4. Do you have a preferred testing method? Still up for discussion.

5. What physical hypotheses about earthquake predictability have motivated your research? Static and/or dynamic stress transfer, Gutenberg-Richter versus Characteristic earthquakes

What Area Do They Cover?

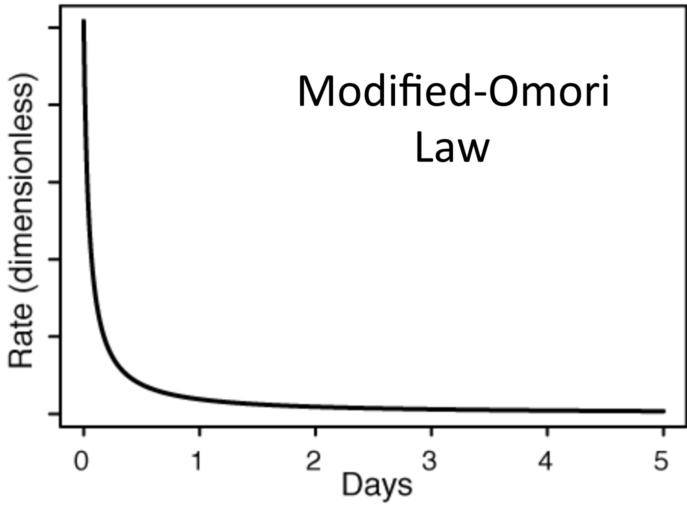
Aftershocks occur in the general region of the mainshock.

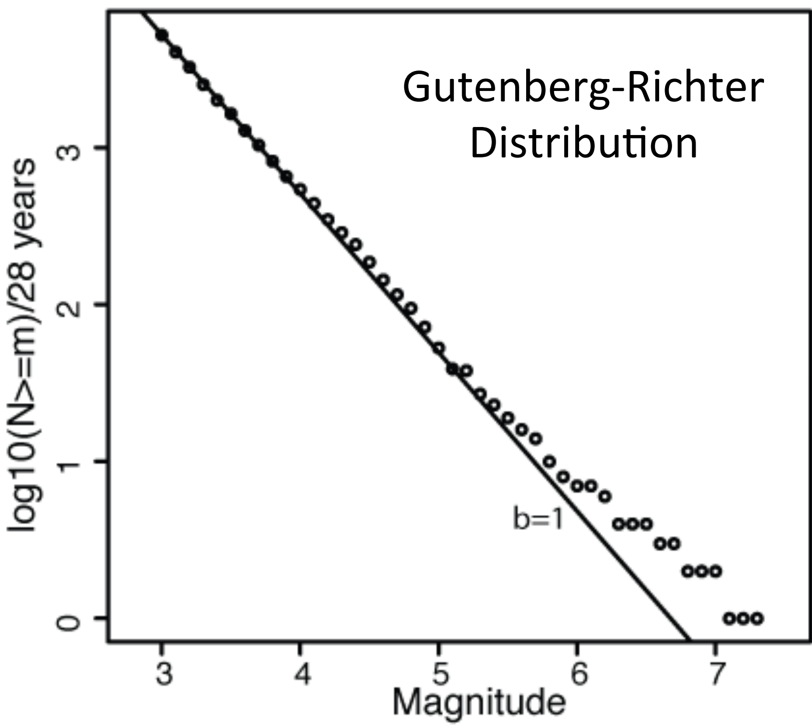
Up to about 1 – 2 fault lengths away.

In the case of a large aftershock at the edge of the zone, the zone will get larger.

The people we are warning, felt the mainshock or should be aware of it.

Reasenberg and Jones, Science, 1989





Probability of earthquakes during an aftershock sequence as a function of time and Magnitude.

What is the Magnitude Range?

(including bigger ones)

Most Aftershocks Are Smaller

1994 Northridge Earthquake Magnitude 6.7
Number of Aftershocks within 30 km of Mainshock
In the first week

Minimum Magnitude	Observed Number	Expected Number
3	310	340
4	42	34
5	6	3.4
6	0	0.34
7	0	0.034

How Long is the Time Period?

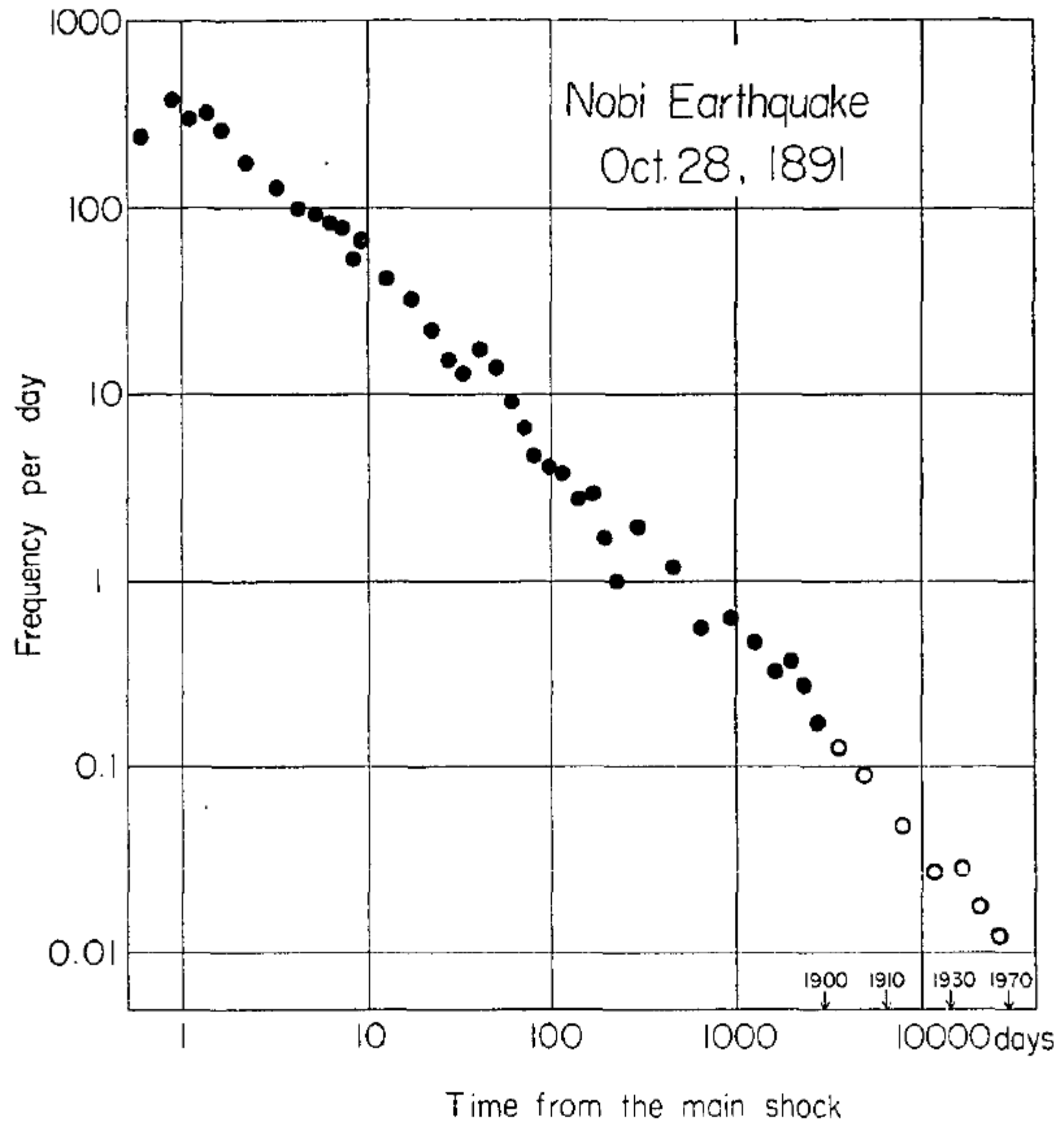
The Rate of Aftershocks Decays at About 1/time

1994 Northridge Earthquake Magnitude 6.7
Number of Aftershocks in 1 day
Magnitude 2 or larger, within 30 km of Mainshock

When	Observed Number	Expected Number
First Day (½ – 1½)	420	733
Tenth Day	44	70
100th Day	4	7.1
1000th Day	0	0.71
10000th Day	? until 2021	0.071

The Long Lives of Aftershocks

Aftershocks of the Magnitude 8¼ Nobi Earthquake of 1891



Forecasts With Respect to Urban Planning for Recovery

Forecast for a Magnitude 7 Mainshock

Stage		
1. Emergency Response (search and rescue, fire fighting, shelters, damage assessment)		
2. Restoration (restore utilities, debris removal, temporary repairs)		
3. Reconstruction (structures replaced to pre-disaster levels)		
4. Betterment (major projects improve community to a new standard)		
5. Long-Term (life with a new normal)		

Forecasts With Respect to Urban Planning for Recovery

Forecast for a Magnitude 7 Mainshock

Stage	**Dominant Time Period** (Kobe, Northridge, Christchurch)	
1. Emergency Response (search and rescue, fire fighting, shelters, damage assessment)	0 to14 days	
2. Restoration (restore utilities, debris removal, temporary repairs)	14 days to 1 year	
3. Reconstruction (structures replaced to pre-disaster levels)	1 to 3 years	
4. Betterment (major projects improve community to a new standard)	3 to 10 years	
5. Long-Term (life with a new normal)	10 to 50 years	

Forecasts With Respect to Urban Planning for Recovery

Forecast for a Magnitude 7 Mainshock

Stage	**Dominant Time Period** (Kobe, Northridge, Christchurch)	**Probability of an Aftershock with Magnitude 6 or larger**
1. Emergency Response (search and rescue, fire fighting, shelters, damage assessment)	0 to14 days	61%
2. Restoration (restore utilities, debris removal, temporary repairs)	14 days to 1 year	33%
3. Reconstruction (structures replaced to pre-disaster levels)	1 to 3 years	11%
4. Betterment (major projects improve community to a new standard)	3 to 10 years	11%
5. Long-Term (life with a new normal)	10 to 50 years	13%

Uncertainties

Variability from sequence to sequence by at least a factor of 10. Our forecasts will adapt to each sequence as we collect data.

The probabilities for the largest events could be underestimated by a factor of 10 to 100.

Forecast After a Magnitude 5

Magnitude 5 Mainshock
Forecast for the First Week

Minimum Magnitude	Probability of 1 or more events	Probability of 1 or more events if M≥7 occur 100x more frequently
3	>99%	>99%
4	49%	52%
5	6.5%	12%
6	0.67%	7%
7	0.067%	6.4%

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Challenges for Testing

We can make many forecasts for various areas, time periods, and magnitude ranges with updates each time a new earthquake occurs:

- Which should we test?
- Is there a small set we can test that implies success or failures for the others?

How do we test forecasts of a range of rates or probabilities?

Forecast After a Magnitude 5

Magnitude 5 Mainshock
Forecast for the First Week

Minimum Magnitude	Expected Number	Probability of 1 or more events
3	6.7	99%
4	0.67	49%
5	0.067	6.5%
6	0.0067	0.67%
7	0.00067	0.067%
8	0.000067	0.0067%

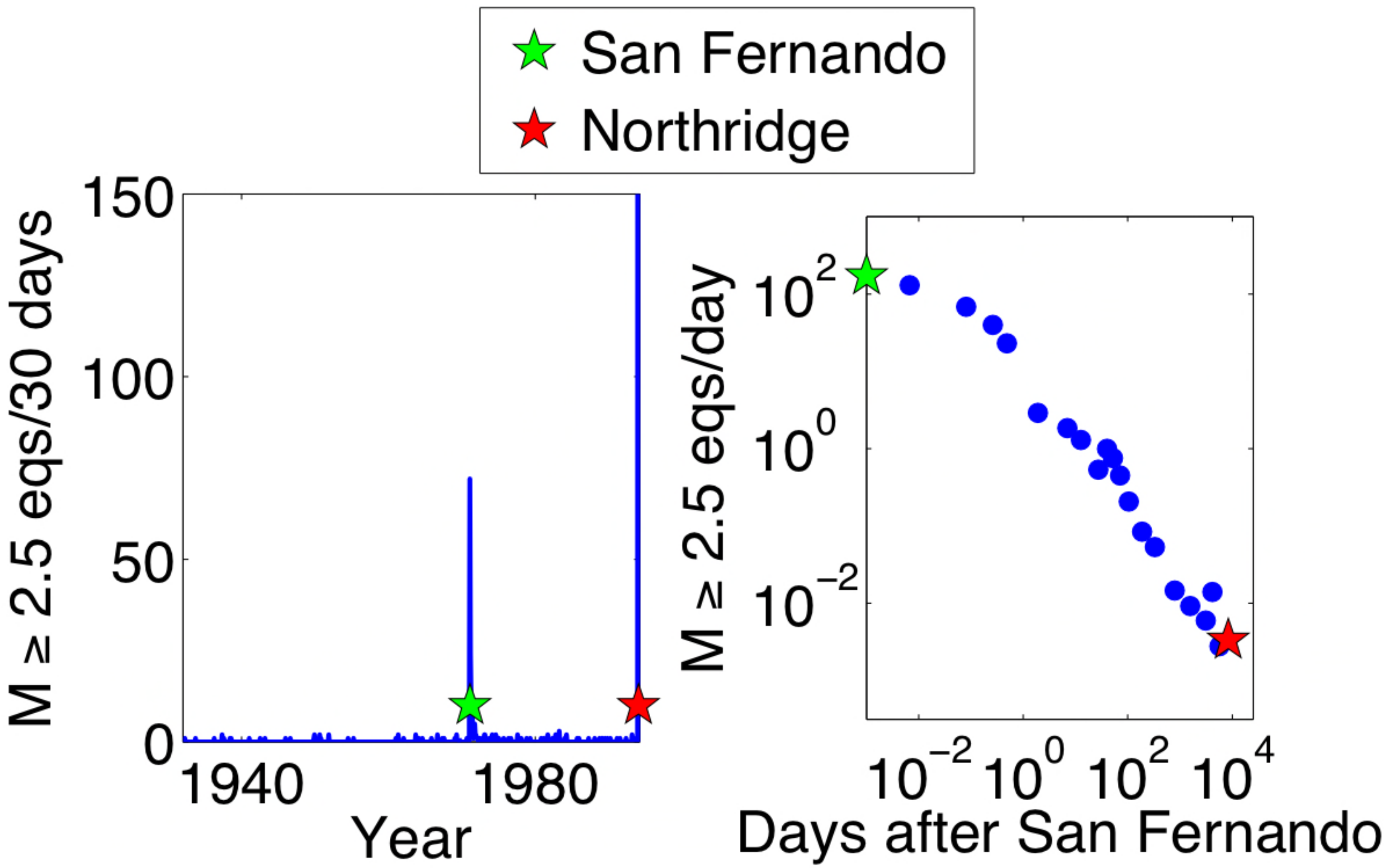
Forecast After a Magnitude 5

Magnitude 5 Mainshock
Forecast for the Fifth Week

Minimum Magnitude	Expected Number	Probability of 1 or more events
3	0.31	27%
4	0.031	3.1%
5	0.0031	0.31%
6	0.00031	0.031%
7	0.000031	0.0031%
8	0.0000031	0.00031%

The Long Lives of Aftershocks

Aftershocks of the 1971 Magnitude 6.5 San Fernando Earthquake



History of OEF at the USGS

1987 – Parkfield Scenario Document
3-day warnings, foreshocks, fault creep, deformation, water wells, magnetics

1989 – Reasenberg and Jones aftershock model

1991 – Agnew and Jones foreshock model

? – California Advisory Plan

2005-2010 - STEP

Recently aftershock probability statements after Haiti, Virginia, and Myanmar earthquakes.

What Is Operational Earthquake Forecasting?
a.k.a. OEF

Currently OEF = Earthquake Clustering
a.k.a. Foreshocks and Aftershocks

Earthquakes trigger other earthquakes.

When you have one earthquake,
the probabilities for other earthquakes go up.

Future developments could include:
transient deformation, slow slip events,
non-volcanic tremor, seismicity patterns,
electromagnetics, …

Semantics

When earthquake happens without obvious ancestors,
it is a mainshock.

Smaller earthquakes follow, they are aftershocks.

If an aftershock occurs that is bigger than the mainshock,
then we rename all previous events foreshocks,
and the biggest aftershock is now the mainshock.

Smaller earthquakes follow, they are aftershocks.

……

The Physics Fine Print: all earthquakes are the same, we can’t tell foreshocks, mainshocks and aftershocks apart.

How Many Aftershocks?

Bigger Mainshocks Produce More Aftershocks

Magnitude of Mainshock	Expected number of aftershocks Magnitude 3 or larger In the first week
5	6.7
6	67
7	670
8	6700

Forecast After a Magnitude 7

Magnitude 7 Mainshock
Forecast for the First Week

Minimum Magnitude	Expected Number	Probability of 1 or more events
3	670	>99%
4	67	>99%
5	6.7	99%
6	0.67	50%
7	0.067	6.5%
8	0.0067	0.66%