Forecasting and Nowcasting Major Earthquakes

An Automated Cloud-Based Approach

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Chairman, Open Hazards Group

Topics:

Science

Applications

Tohoku, Japan

Earthquake and Tsunami

March 11, 2011

How do we estimate risk from these events?

What does this mean for the insurance industry?

Pricing Earthquake Risk: Current Practice

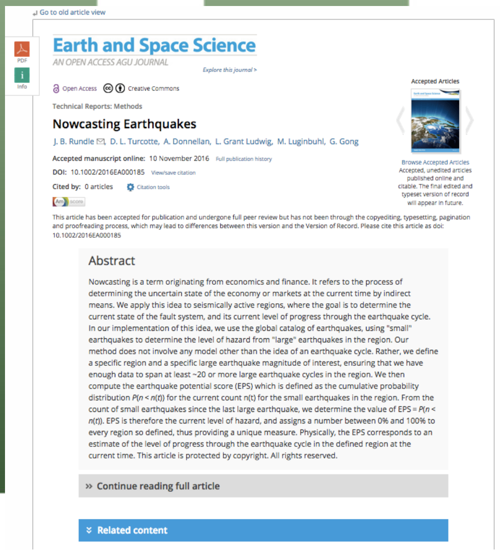
Science	Engineering	Economics	Products
Earthquake forecast model →	Ground shaking model →	Economic loss model →	Pricing of insurance & financial securities
Poisson Log Normal BPT Fault models Pattern Analysis AMR ETAS NTW Nowcast Etc.	Attenuation PGA/PGV Lquifaction Surface geology Basin structure Etc.	EP curves Building damage Socioeconomic data Supply chain disruption Lost income Lifelines Etc.	CAT Bonds SPVs Warrants Traders Hedge Funds Options Muni Bonds Equities Etc.

The Science

Nowcasting and Forecasting

Nowcasting Earthquakes

JBR et al. (2016)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Technical Reports: Methods

Nowcasting Earthquakes

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Accepted manuscript online: 10 November 2016 Full publication history
DOI: 10.1002/2016EA000185 View/save citation
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Abstract

Nowcasting is a term originating from economics and finance. It refers to the process of determining the uncertain state of the economy or markets at the current time by indirect means. We apply this idea to seismically active regions, where the goal is to determine the current state of the fault system, and its current level of progress through the earthquake cycle. In our implementation of this idea, we use the global catalog of earthquakes, using "small" earthquakes to determine the level of hazard from "large" earthquakes in the region. Our method does not involve any model other than the idea of an earthquake cycle. Rather, we define a specific region and a specific large earthquake magnitude of interest, ensuring that we have enough data to span at least ~20 or more large earthquake cycles in the region. We then compute the earthquake potential score (EPS) which is defined as the cumulative probability distribution $P(n < n(t))$ for the current count n(t) for the small earthquakes in the region. From the count of small earthquakes since the last large earthquake, we determine the value of EPS = $P(n < n(t))$. EPS is therefore the current level of hazard, and assigns a number between 0% and 100% to every region so defined, thus providing a unique measure. Physically, the EPS corresponds to an estimate of the level of progress through the earthquake cycle in the defined region at the current time.

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Related content

Nowcasting

Forecasting is a probability of future activity in the hazard (earthquake) cycle

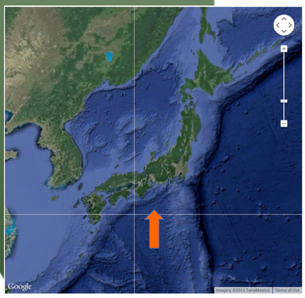
Nowcasting describes the current state of the hazard cycle

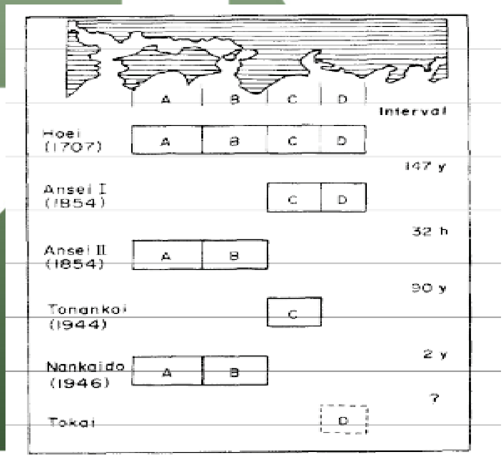
The term “Nowcasting” was first used to describe the current state of the economic/business cycle

Earthquake Cycle Example: Nankai Trench, Japan

M Ando, Tectonophysics, v27, p112 (1975)

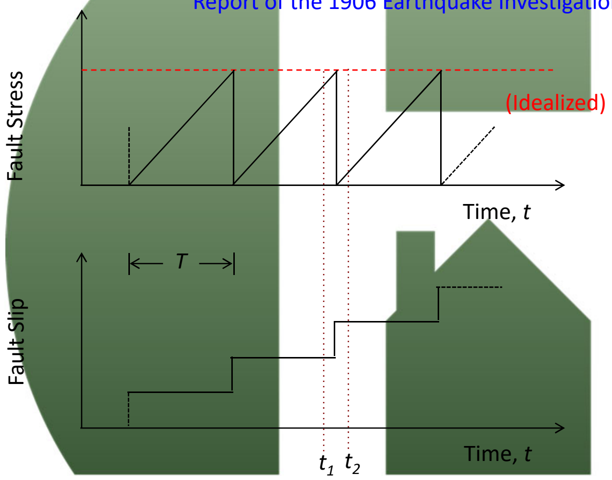
- Data from historic writings in Japan
- The basic idea of the earthquake "cycle" started in Japan using historical data





The Earthquake Cycle Arises from Elastic Rebound

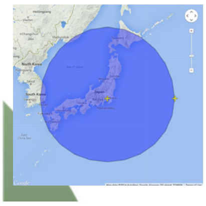
Report of the 1906 Earthquake Investigation (1910)



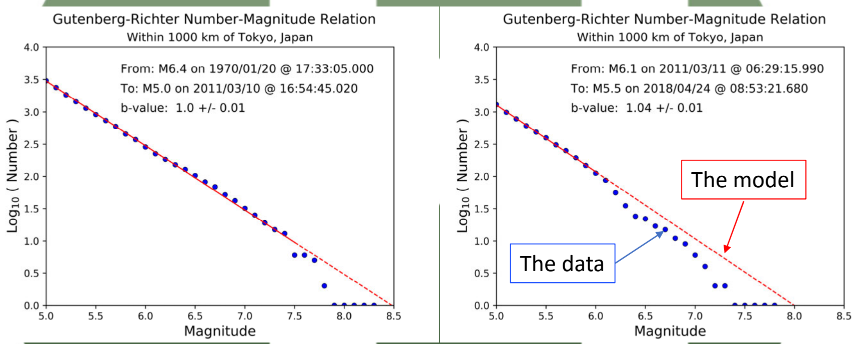
Harry Fielding Reid (1859-1944)

But: How do we measure the time-dependent state of stress?

Example: Magnitude-Frequency Data is Modeled by the Gutenberg-Richter Law



1000 km Around Tokyo (Accessed April 24, 2018)



Before the 3/11 M9.1 Mainshock

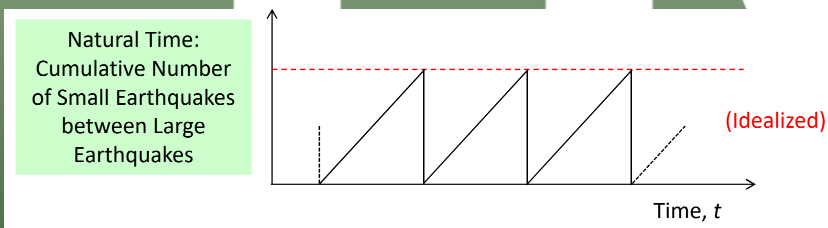
After the M7.7 Aftershock

Basic idea of Nowcasting: Deficiency of large earthquakes must be filled in eventually

A consequence of the ergodic dynamics of seismicity (e.g., Tiampo et al., 2007)

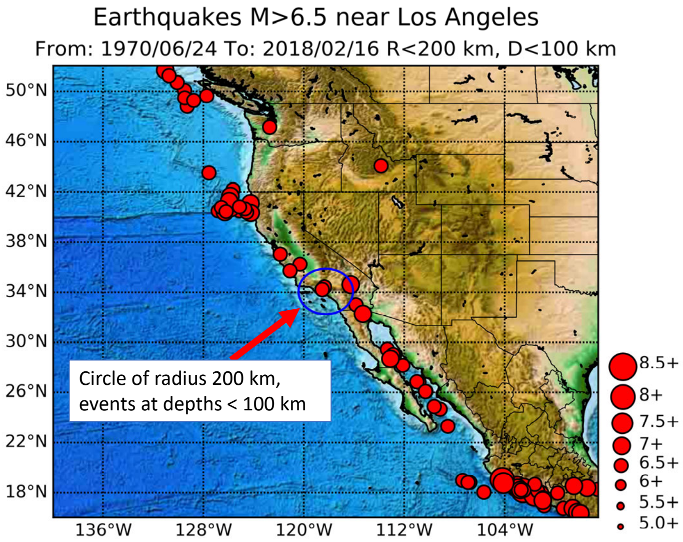
Basic Nowcasting Includes Elastic Rebound via Small Earthquake Proxy Data

Example:
"Large" EQ: $M_L > 6$
"Small" EQ: $6 > M_S > 4$



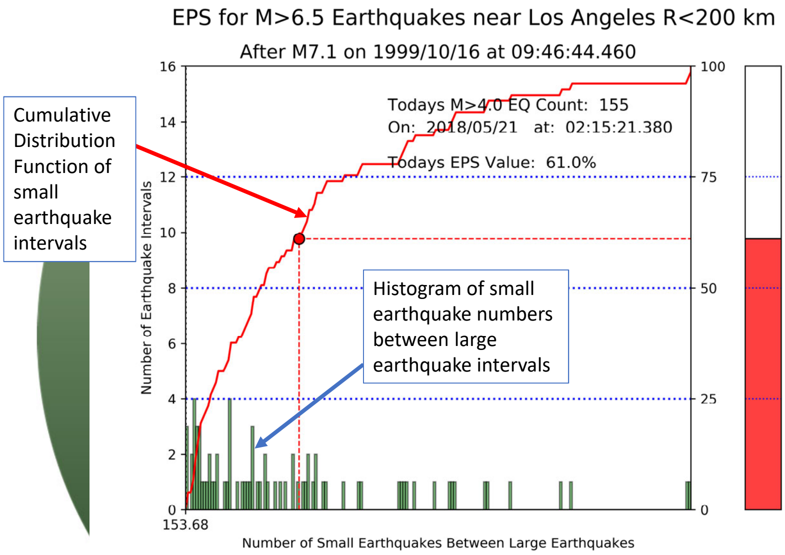
Accumulating small earthquakes are readily observable proxy data, unlike stress

Seismicity around Los Angeles



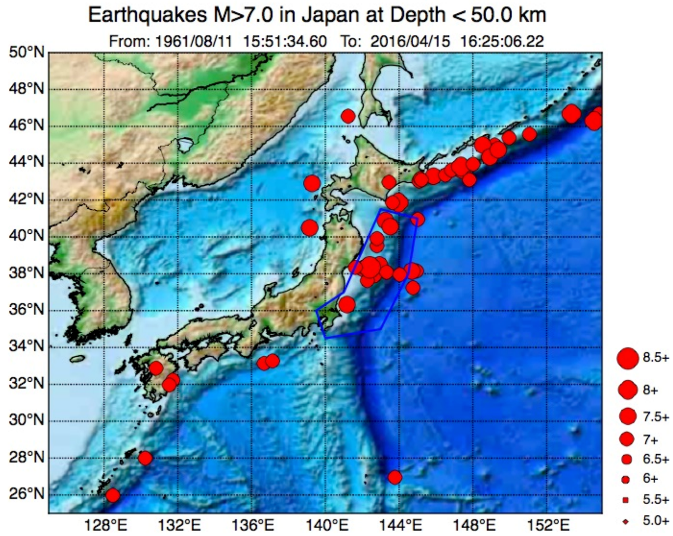
Los Angeles

Earthquake Potential Score



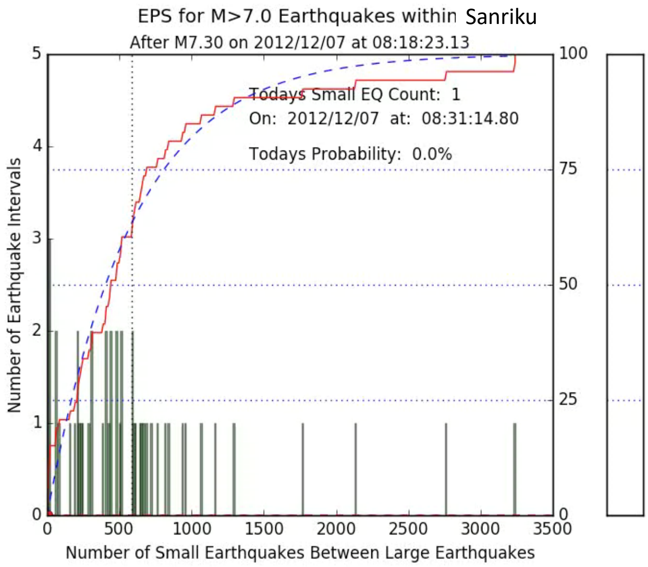
Los Angeles

Example: Nowcasting the Sanriku Trench



Earthquake Potential Score, Sanriku Trench

Computed 3/31/2017. Depths < 50 km



Sensitivity Analysis

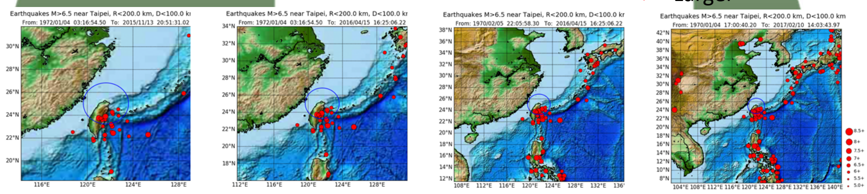
Varying region sizes and completeness magnitudes

Fixed Conditions:

1) Computed for M>6.5 2) 200 km radius around cities 3) Depth < 100 km

1) Change the large region diameter: 1500 km, 2000 km, 3000 km, 4000 km

Larger



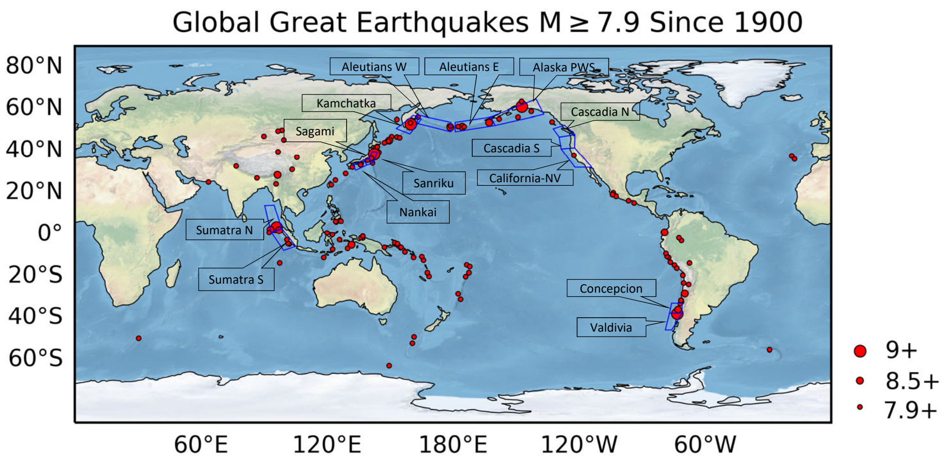
1500 x 1500 km | 2000 x 2000 km | 3000 x 3000 km | 4000 x 4000 km

2) Change the completeness threshold for San Francisco and Los Angeles calculations from M3.0 to M4.0

Result: Under reasonable conditions, EPS changes by only about +/- 10%

Nowcasting Great Earthquake and Tsunami

Source Regions



Enhanced Nowcasting adds Two Simple Model Ideas

- **Definition: Cutoff Date**. Date after which catalog is assumed to be complete at the defined completeness level
  - For M>6, cutoff date is apparently 1950 (next slide)
  - Sensitivity tests show cutoff date of 1960 gives similar results
- **Idea 1.** Small earthquakes that occur after the cutoff date are counted. Small earthquake numbers prior to the cutoff date are estimated using the average rate from after the cutoff date
- **Idea 2.** Current estimated magnitude m is computed as:

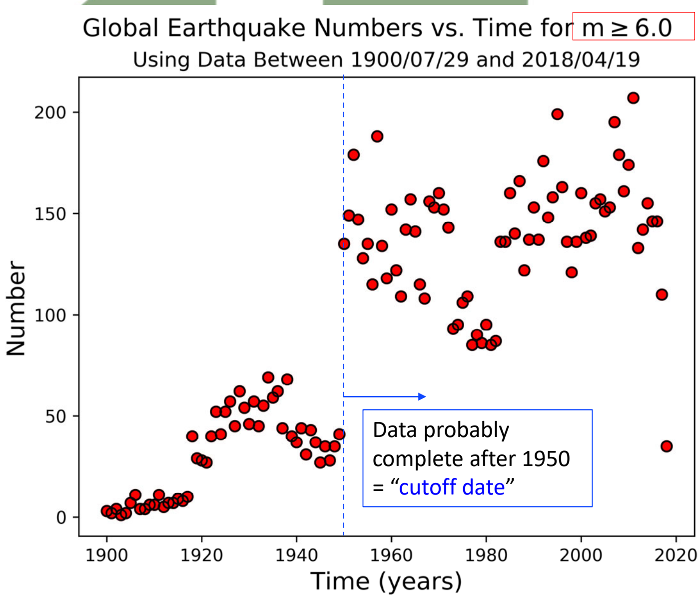
$$m = m_C + (1/b)\ \mathrm{Log}_{10}(N)$$

Where:

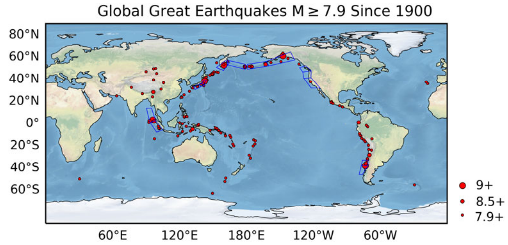
N = Natural time count of small earthquakes since last large earthquake

m_C = Catalog completeness magnitude

Global Seismicity, 1900 - 2018

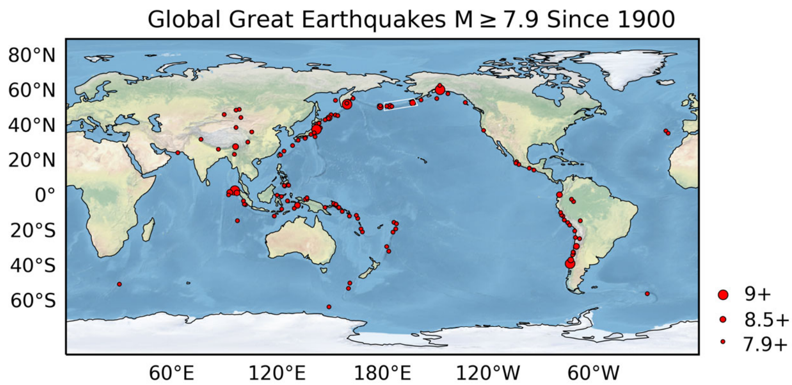


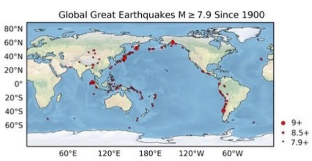
Summary Data

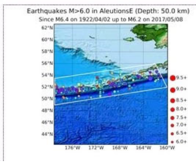


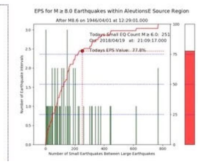
Location (Source Polygon)	EPS(%) Score on 2018/05/28 at 12:40:09 PT	Date Most Recent Large EQ in Polygon	Mag Most Recent Large EQ in Polygon	Nat. Time Count on 2018/05/28 at 12:40:09 PT	Current Estimated Magnitude	Mean Count Worldwide	Std Dev Worldwide	Number Large EQs Worldwide in Catalog
AleutionsE	77.8	1946/04/01	8.6	251	8.2	173.07	176.57	93
Kamchatka	70.4	1952/11/04	9	199	8.2	173.07	176.57	93
CascadiaS	69.4	1922/01/31	7.3	26	7.3	21.18	20.52	670
CascadiaN	55.3	1946/06/23	7.5	28	7.4	32.88	31.05	454
California-Nevada	43.0	1906/04/18	7.9	69	7.7	118.72	128.38	130
AleutionsW	40.7	1965/02/04	8.7	100	7.9	173.07	176.57	93
AlaskaPWS	38.9	1964/03/28	9.2	88	7.8	173.07	176.57	93
Sagami	25.9	1923/09/01	8.1	64	7.7	173.07	176.57	93
SumatraN	25.9	2004/12/26	9.1	62	7.7	173.07	176.57	93
Sanriku	25.9	2011/03/11	9.1	58	7.7	173.07	176.57	93
SumatraS	25.9	2005/03/28	8.6	56	7.6	173.07	176.57	93
Valdivia	20.4	1960/05/22	9.5	46	7.6	173.07	176.57	93
Concepcion	18.5	2010/02/27	8.8	40	7.5	173.07	176.57	93
Nankai	13.0	1946/12/20	8.3	22	7.3	173.07	176.57	93

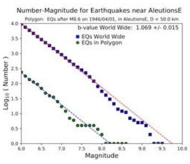
Aleutians E Polygon Source Region



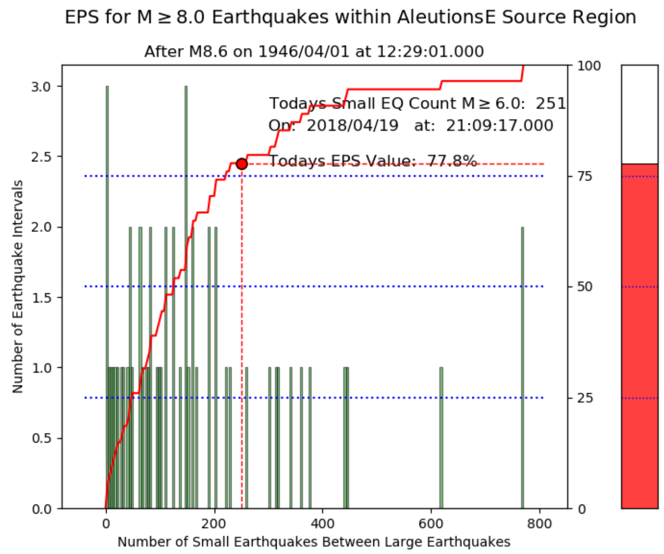




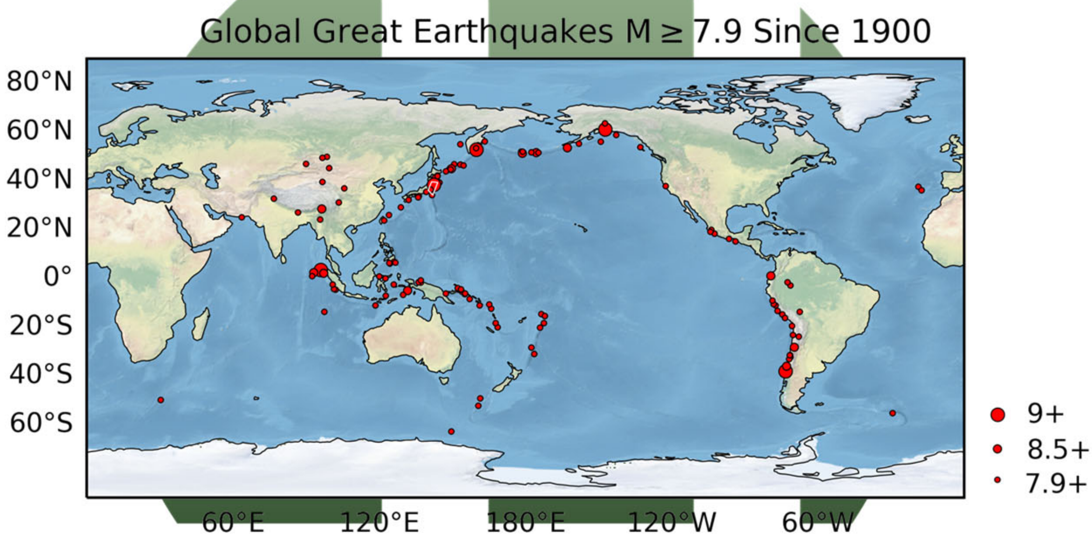




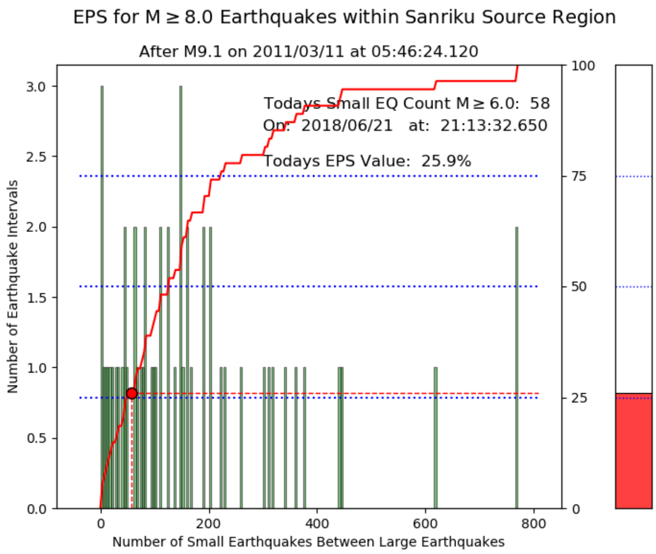
Enhanced Nowcast for Aleutians E



Sanriku Coast Polygon Source Region



Enhanced Nowcast for Sanriku Coast Source Region



Earthquake Forecasting

Current Practice

- Expert elicitation is frequently used in forecasting, meaning that backtesting is not possible
- Most/many current forecasts use time-independent Poisson statistics in forecasting
- Poisson forecasts have the property that they have no memory of past events
- An example is the current UCERF3 forecast for California, which has not been backtested

From Nowcasts to Forecasts

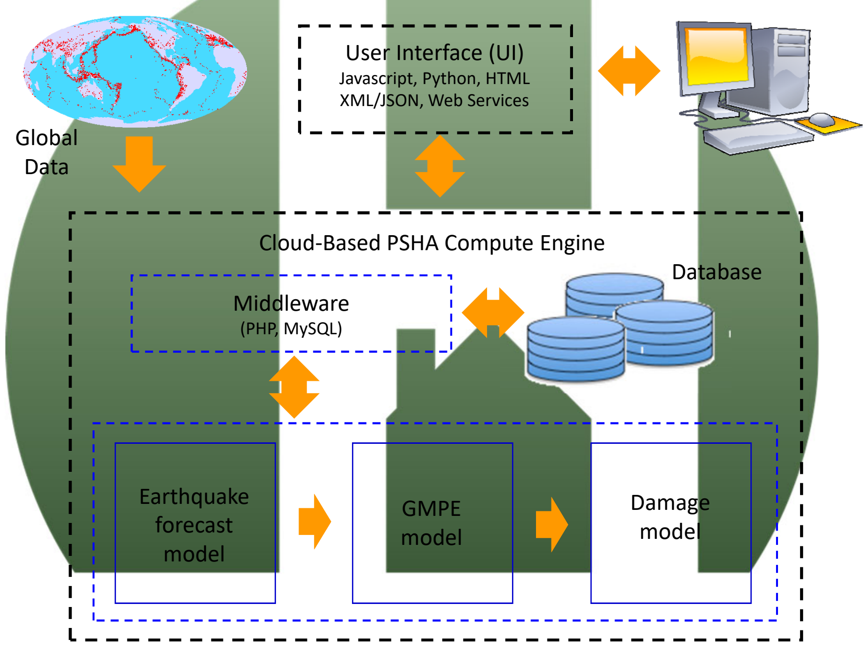
Forecasting with the Natural Time Weibull Method

JR Holliday et al. (2014)

- We begin by counting small earthquakes since the last large earthquake (Nowcasting)
- We build on the Nowcast by projecting the count forward in time using the current rate of small earthquake activity
- We combine these ideas with Weibull (1952) statistics, which are commonly used for engineering failure analysis
- The result is a fully automated computation of probability of future large earthquake occurrence
- Automation allows backtesting and optimization
- We have built this technology into a series of automated cloud-based web sites:

www.openhazards.com

Open Hazards PSHA Cloud Computational Framework



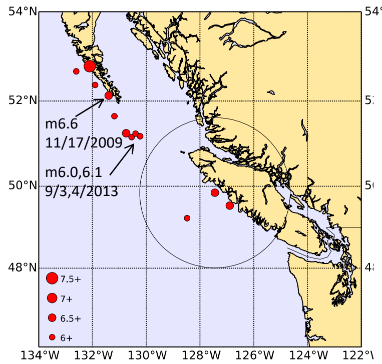
Automated forecasting and risk analysis allows rigorous backtesting.

Expert elicitation generally does not allow rigorous backtesting

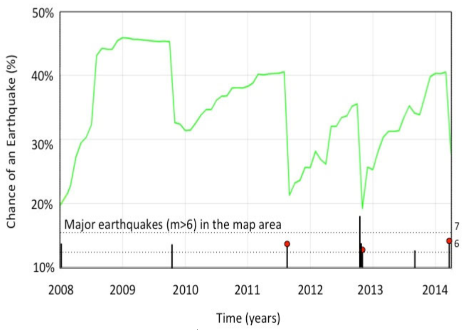
Example: Vancouver Island Earthquakes, NTW Forecast

Latest Significant Event was M6.6 on 4/24 /2014

JR Holliday et al. (2014)

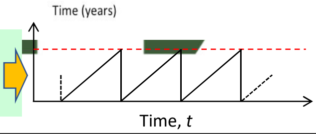


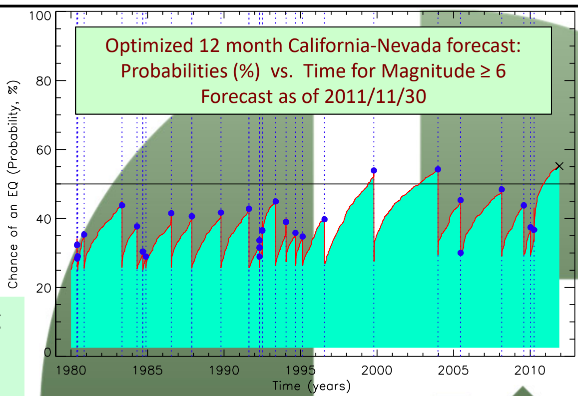
Chance of M>6 earthquake in circular region of radius 200 km for next 1 year. Data accessed 4/26/2014



Observed Behavior

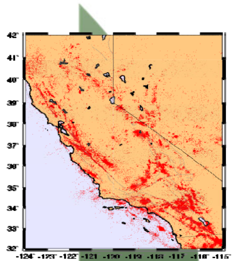
Idealized Expected Behavior



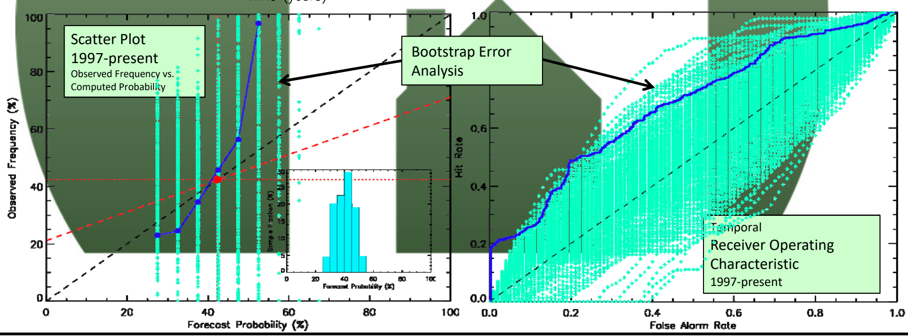


Optimal California-NV Forecast

Optimal forecasts via backtesting, using common validation and verification testing procedures.



Automating Forecasts Allows Backtesting and Optimizing!



Applications/Products

The Open Hazards Group

Risk Analysis and Management Reimagined

Risk: Applications and Products

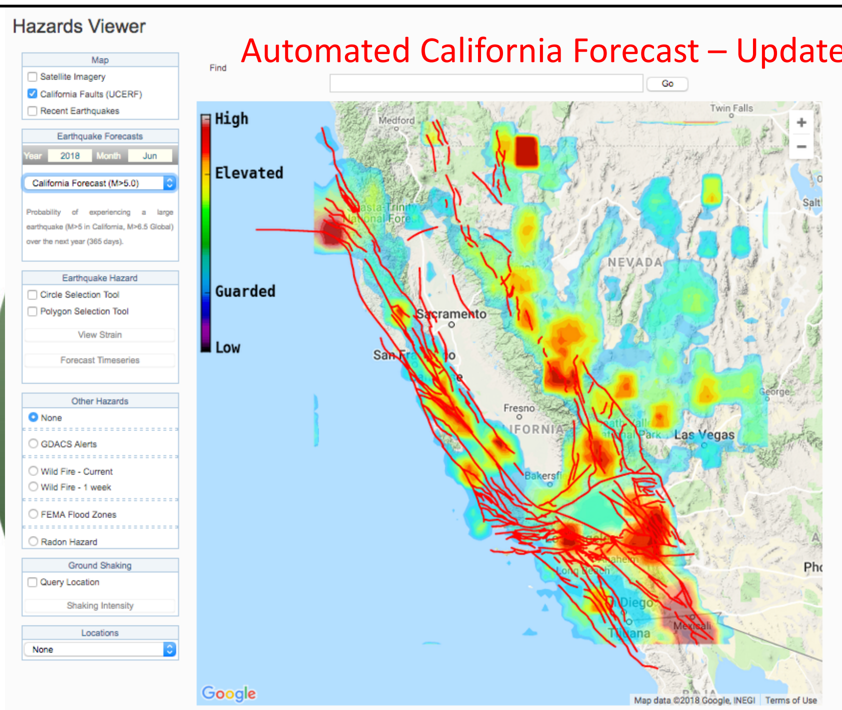
The Open Hazards Group

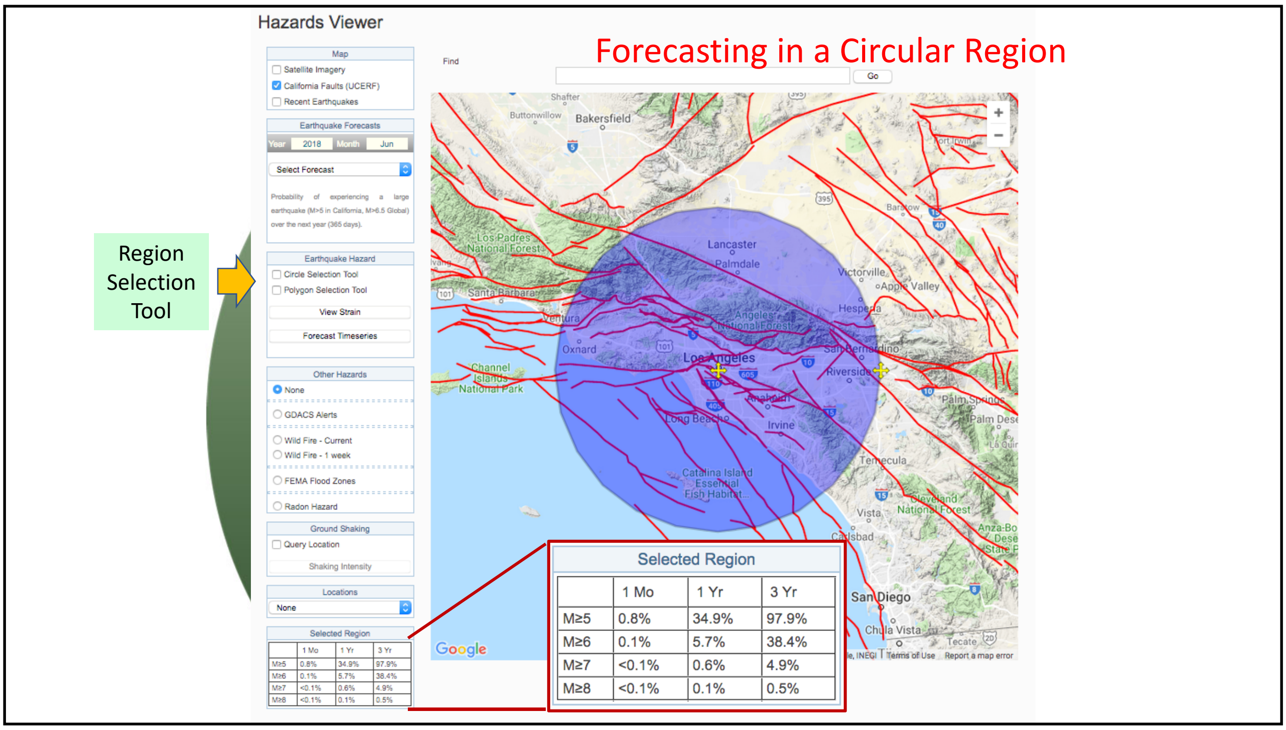
- Public web site
  - NTW forecasts web app
  - Ground shaking web app
  - Structural damage factor web app
- Residential seismic safety reports
- Commercial seismic safety reports
- Cat bond analysis
- Natural hazard disclosures (required in California for transfer of property)
- Financial trading models for hedge funds

Automated Forecasting in the Cloud

www.openhazards.com

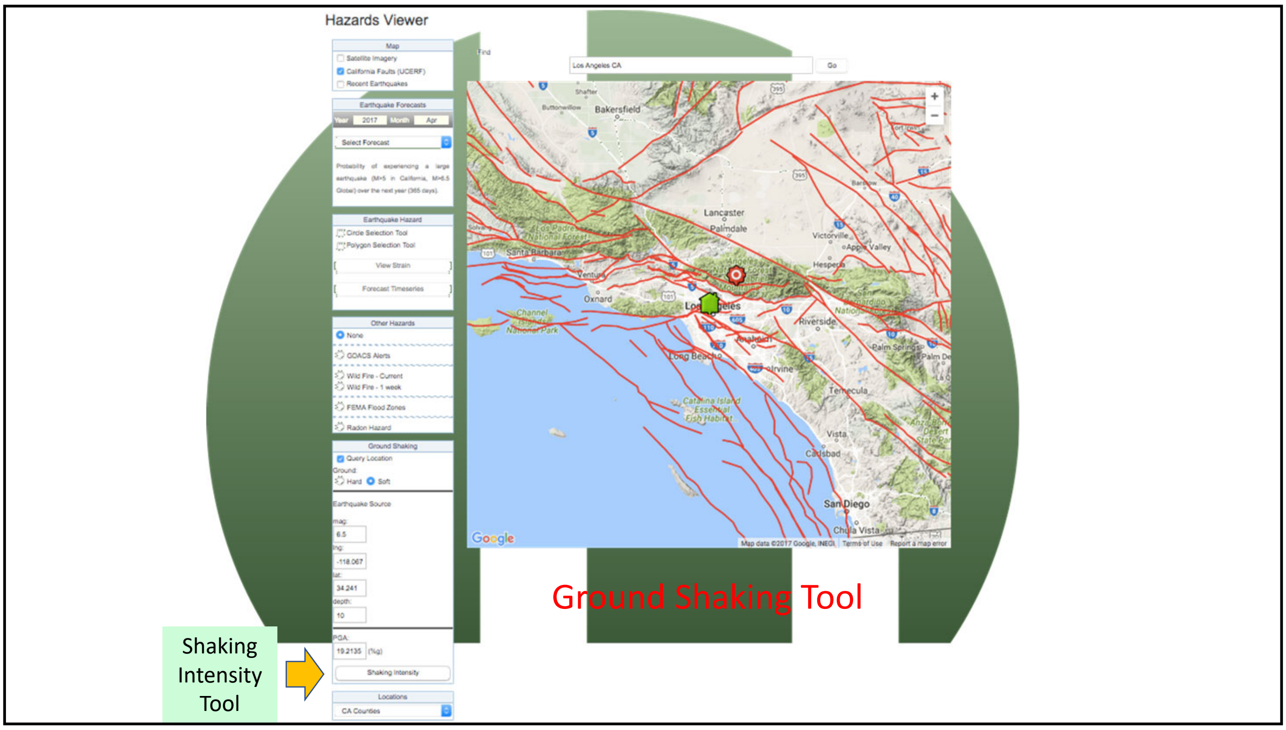
Automated California Forecast – Updated Nightly





Selected Region

	1 Mo	1 Yr	3 Yr
M≥5	0.8%	34.9%	97.9%
M≥6	0.1%	5.7%	38.4%
M≥7	<0.1%	0.6%	4.9%
M≥8	<0.1%	0.1%	0.5%



Risk Assessment For Likely Ground Shaking

Report Generated:	Tue, 25 Apr 2017
Location:	(34.052115021165484, -118.27862620353699)
Source:	(34.24070193917228, -118.06713938713074)
PGA:	19.2135 (%g)
MMI:	VII

Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

A descriptive table of Modified Mercalli Intensity is available from ABAG (Association of Bay Area Governments). A table of intensity descriptions with the corresponding peak ground acceleration (PGA) and peak ground velocity (PGV) used by the USGS is given below.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Residential Seismic Safety Report

For homeowners, property owners and renters

You need reliable information and advice. How safe are your loved ones, home, and belongings from earthquakes? What options do you have to reduce your risk?

For conscientious homeowners, property owners, and renters, OpenHazards provides a detailed earthquake forecast and home safety assessment. Decide on the most dependable and cost-effective steps to mitigate your risk. With an OpenHazards Seismic Safety Report, the information you need is at your fingertips.

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And more — just view a sample report and see. [PDF] SAMPLE REPORT.PDF

Your home may be worth hundreds of thousands of dollars. Earthquake insurance could cost $1,500 a year. Peace of mind for your family is priceless. Make informed decisions about your risk with an OpenHazards Seismic Safety Report.

We are currently experiencing technical difficulties with our ordering system. If you'd like to order a report, please use the Contact Us page.

Residential Seismic Safety Report

1 Introduction

Whether you own, plan to buy, or rent property, you need the best advice possible about the financial and personal risks you might face. OpenHazards offers the only openly accessible tool to help you answer questions you may have about earthquake hazards in your area.

Welcome to the world of seismic safety.

What are the chances your home, condominium or apartment building could be badly damaged during or after an earthquake? After the first shaking stops, how vulnerable are you to associated hazards, more shaking (aftershocks), ground rupture (displacement), landslides, fires, soil liquefaction, tsunamis, or floods? How would the value of your property be affected? What can you do to protect your investment? Or if you haven't yet invested, what do you need to know to make a good decision?

OpenHazards seismic forecasting is a new concept in seismic safety. Both the OpenHazards website and personalized reports are designed to help you make critical decisions that affect your life and property.

Both owners and renters can benefit from an OpenHazards Seismic Report

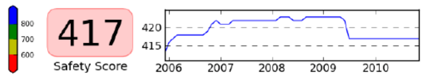
OpenHazards reports are particularly useful to prospective home-buyers. The reports can help you and your realtor accurately compare seismic risks for several properties. This allows you to choose the safest home possible.

We calculate two figures of merit for this purpose: the *Safety Score* (OHSS), and the *Hazard Discounted Value* (HDV). The Safety Score is an index reflecting a likelihood of damage to personal property or to your structure. The Hazard Discounted Value calculates the home value discounted by the effects of structural damage to the home in an average likely earthquake. By comparing the reports for two homes, you can assess the risk of loss quantitatively. The safety score may also be used to loosely compare risk of injury.

Property Synopsis

Property Address: 126 Huerta Place, Davis, CA 95616, USA
Declared Value: $1,500,000
Hazard Discounted Value: $1,305,983

Residence: Single Family
Year Built: 1967
 # Stories: 2
House Size: 2500 sq. ft.
Construction: Wood Frame
Soil Type: Hard Rock



This property has a Safety Score of 417 indicating it is at high risk of structural damage over the coming years. Earthquake insurance might be appropriate. Note that this calculation is based on home descriptions you supplied. OpenHazards does not verify the accuracy of the home details.

	Within 1 Year	Within 5 Years	Within 10 Years	Within 30 Years
At Least $9,000 Loss (1% Damage)	0.06% Chance	0.28% Chance	0.56% Chance	1.68% Chance
At Least $45,000 Loss (5% Damage)	0.02% Chance	0.09% Chance	0.18% Chance	0.53% Chance
At Least $90,000 Loss (10% Damage)	<0.01% Chance	0.03% Chance	0.05% Chance	0.15% Chance
At Least $135,000 Loss (15% Damage)	<0.01% Chance	<0.01% Chance	0.02% Chance	0.05% Chance
At Least $180,000 Loss (20% Damage)	<0.01% Chance	<0.01% Chance	<0.01% Chance	0.02% Chance

This table indicates the likelihood of damage and financial loss within a future time interval. The vertical columns designate the time interval from today, and the horizontal rows designate the ranges of loss. The *15% Damage* threshold indicates the typical deductible for residential earthquake insurance.

Risk Calculations: EP Curves

Residential Seismic Safety Report

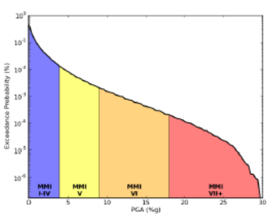


Figure 5: Peak ground acceleration—measured as a percent of gravity (%g)—exceedance probability curve calculated at your home's location. Shaking below MMI V (about 4%g) is generally not felt by individuals.

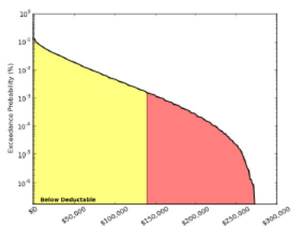
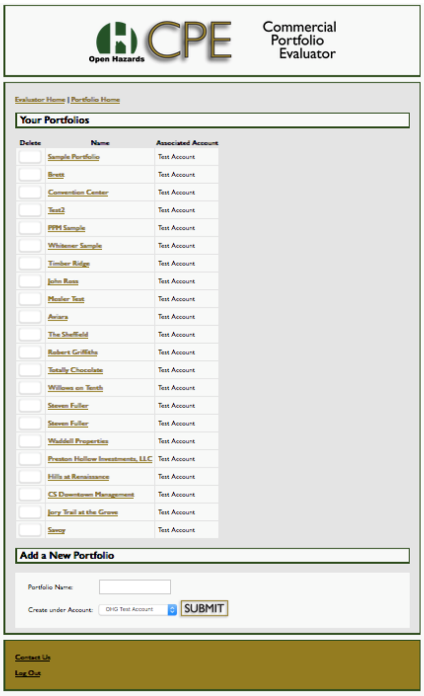
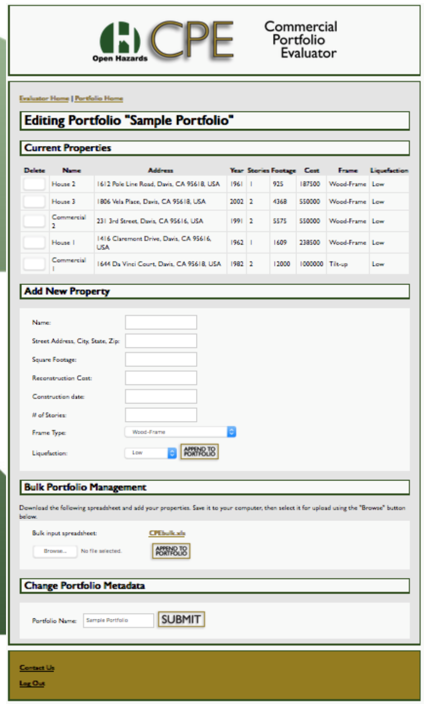
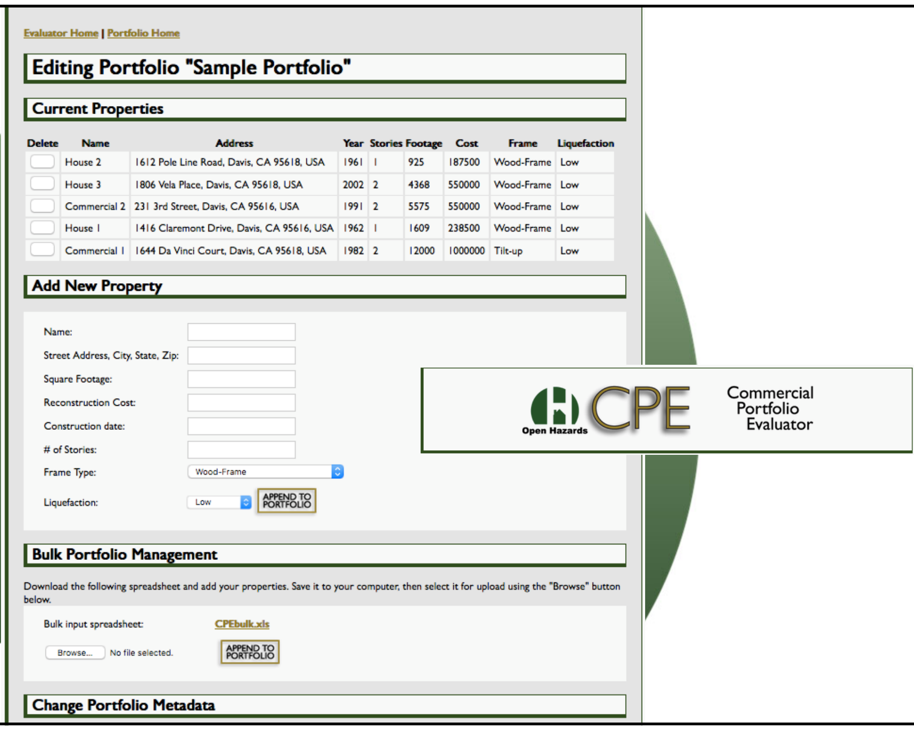


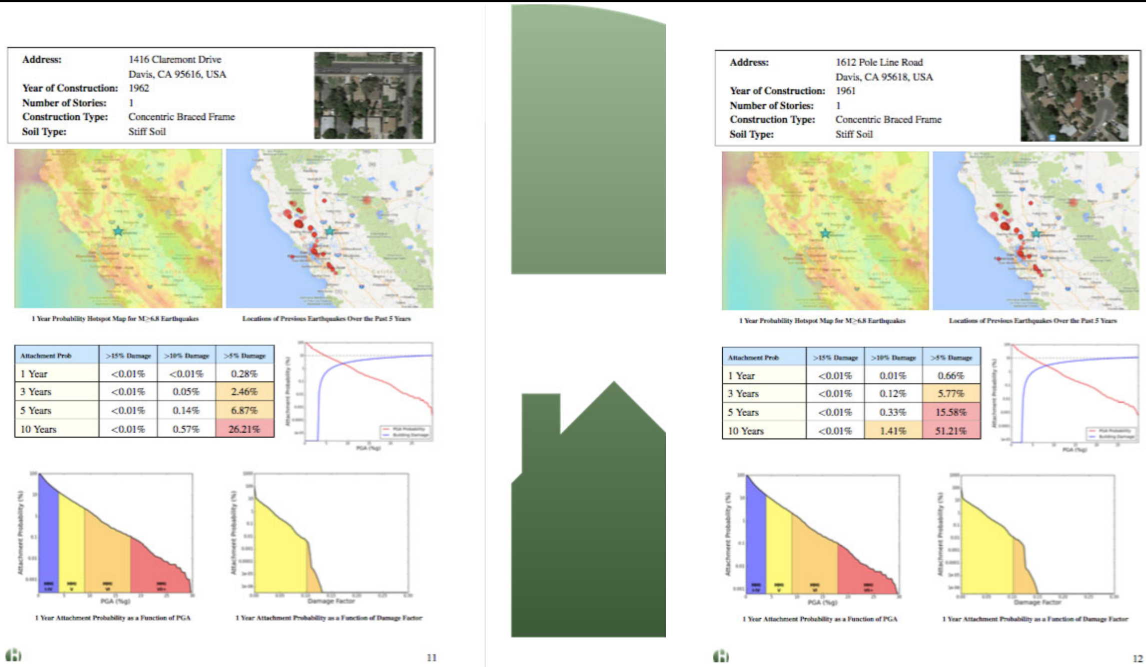
Figure 7: Dollar loss exceedance probability curve for your home. Damage values below the standard deductible (15% of the value of your home) are indicated in yellow. Damage values above the standard deductible are indicated in red.



Automated Commercial Portfolio Evaluator







Address:	1416 Claremont Drive, Davis, CA 95616, USA
Year of Construction:	1962
Number of Stories:	1
Construction Type:	Concentric Braced Frame
Soil Type:	Stiff Soil

1 Year Probability Hotspot Map for M≥6.8 Earthquakes

Locations of Previous Earthquakes Over the Past 5 Years

Attachment Prob	>15% Damage	>10% Damage	>5% Damage
1 Year	<0.01%	<0.01%	0.28%
3 Years	<0.01%	0.05%	2.46%
5 Years	<0.01%	0.14%	6.87%
10 Years	<0.01%	0.57%	26.21%

1 Year Attachment Probability as a Function of PGA

1 Year Attachment Probability as a Function of Damage Factor

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Address:	1612 Pole Line Road, Davis, CA 95618, USA
Year of Construction:	1961
Number of Stories:	1
Construction Type:	Concentric Braced Frame
Soil Type:	Stiff Soil

1 Year Probability Hotspot Map for M≥6.8 Earthquakes

Locations of Previous Earthquakes Over the Past 5 Years

Attachment Prob	>15% Damage	>10% Damage	>5% Damage
1 Year	<0.01%	0.01%	0.66%
3 Years	<0.01%	0.12%	5.77%
5 Years	<0.01%	0.33%	15.58%
10 Years	<0.01%	1.41%	51.21%

1 Year Attachment Probability as a Function of PGA

1 Year Attachment Probability as a Function of Damage Factor

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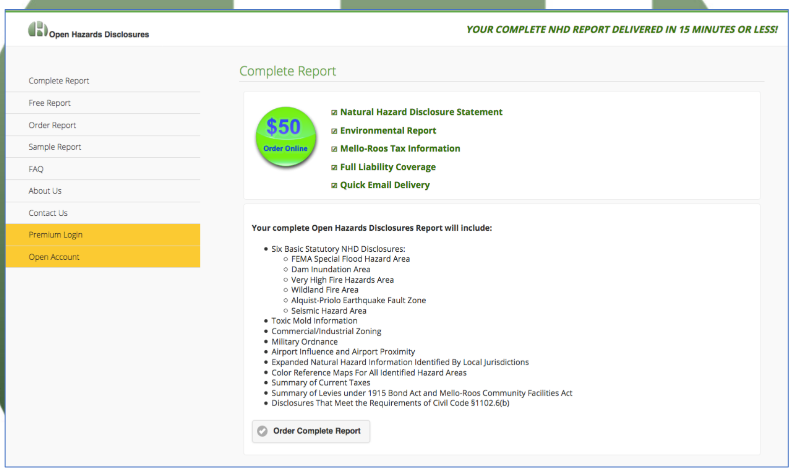
Pages from Sample Commercial Report

Natural Hazards Disclosures

for Transfer of Residential Real Estate in California



Summary

- Forecasting: Computing the probability of future activity
- Nowcasting: Determining the current state of progress through the hazard cycle
- Uses: Ranking the current seismic risk of cities and tsunami source regions world wide
- Sensitivity Analysis:
  - ✓ Need to use a completeness threshold that is relatively uniform over the entire region
  - ✓ Need to ensure that statistics are relatively uniform across the large geographic region

Thank you for your attention

The Open Hazards Group

www.openhazards.com

About Me

Distinguished Professor of Physics and Geology, University of California, Davis

Co-Founder of Open Hazards Group and Chair of the Board, Davis, California

Executive Director Emeritus of the APEC Cooperation for Earthquake Simulations (ACES)

A Senior Advisor to the Association of Pacific Rim Universities (APRU)

Visiting Professor at Tohoku University at the APRU Multihazards Hub, Tohoku University, Sendai, Japan

John was Chair (1994-1996) of the scientific Advisory Council to the Southern California Earthquake Center. He has been a Distinguished Visiting Scientist at the Jet Propulsion Laboratory, Pasadena, CA (1995-present), is currently an External Professor at the Santa Fe Institute, and is a Fellow of the American Physical Society (2005), the American Geophysical Union (2008), and the American Association for the Advancement of Science (2017). Recently, he was a co-winner of the NASA Software of the Year Award (2012). John received his B.S.E from Princeton University (Magna Cum Laude, Phi Beta Kappa, Tau Beta Pi), and M.S. (1973) and Ph.D. (1976) from the University of California at Los Angeles. In addition to natural hazards and earthquakes, he also has professional interests in forecasting, validation of forecasts, and quantitative finance. He currently co-organizes (along with Michael Maoboussin, Will Tracy and Martin Lebowitz) a yearly meeting on risk for the Santa Fe Institute, often held at Morgan Stanley, Inc., in New York. He teaches courses in Risk and Natural Disasters; Complex Systems; and Econophysics and Quantitative Finance at the University of California, Davis.