Status of OEF Development at the USGS

Michael L. Blanpied
USGS Earthquake Hazards Program
mblanpied@usgs.gov

For CSEP Workshop
September 12, 2015

Is USGS already doing OEF?

- Yes, but…
  - Not uniformly, completely, or using best-available and well-tested methods.
  - Not tailored to meet user needs.
- Aftershock forecasts published following larger earthquakes in California by the California Integrated Seismic Network.
  - CISN = USGS, CGS, CalOES, Caltech and UC Berkeley
- USGS issues *ad hoc* formal and informal aftershock probabilities, when requested after major earthquakes, domestic and abroad.
  - Some based on clustering statistics, when available.
  - Some based on time-dependent renewal models.
  - Some based on Coulomb stress calculations.

CISN issues Reasenberg & Jones forecasts following M≥5 California earthquakes

CGS USGS CalOES Caltech UC Berkeley

09/28/2004 Aftershock Probabilities

Tue 28 Sep 2004 11:23 AM PDT

U. S. Geological Survey, Menlo Park, California
U. C. Berkeley Seismological Laboratory, Berkeley, California

This forecast is based on the statistics of aftershocks typical for California. This is not an exact prediction, but only a rough guide to expected aftershock activity. This forecast may be revised as more information becomes available.

MAINSHOCK: Tue 28 Sep 2004 10:15:24 AM PDT MAGNITUDE 6.0

11 km (7 miles) SSE (151 degrees) of Parkfield, CA

STRONG AFTERSHOCKS (Magnitude 5 and larger)

At this time (one hour after the mainshock) the probability of a strong and possibly damaging aftershock IN THE NEXT 7 DAYS is approximately 50 PERCENT.

EARTHQUAKES LARGER THAN THE MAINSHOCK

Most likely, the recent mainshock will be the largest in the sequence. However, there is a small chance (APPROXIMATELY 5 TO 10 PERCENT) of an earthquake equal to or larger than this mainshock in the next 7 days.

WEAK AFTERSHOCKS (Magnitude 3 to 5)

In addition, approximately 30 to 70 SMALL AFTERSHOCKS are expected in the same 7-DAY PERIOD and may be felt locally.

Background Information About Aftershocks

Like most earthquakes, the recent earthquake is expected to be followed by numerous aftershocks. Aftershocks are additional earthquakes that occur after the mainshock and in the same geographic area. Usually, aftershocks are smaller than the mainshock, but occasionally an aftershock may be strong enough to be felt widely throughout the area and may cause additional damage, particularly to structures already weakened in the mainshock. As a rule of thumb, aftershocks of magnitude 5 and larger are considered potentially damaging.

Aftershocks are most common immediately after the mainshock; their average number per day decreases rapidly as time passes. Aftershocks are most likely to be felt in the first few days after the mainshock, but may be felt weeks, months, or even years afterwards. In general, the larger the mainshock, the longer its aftershocks will be felt.

Aftershocks tend to occur near the mainshock, but the exact geographic pattern of the aftershocks varies from earthquake to earthquake and is not predictable. The larger the mainshock, the larger the area of aftershocks. While there is no "hard" cutoff distance beyond which an earthquake is totally incapable of triggering an aftershock, the vast majority of aftershocks are located close to the mainshock. As a rule of thumb, a magnitude 6 mainshock may have aftershocks up to 10 to 20 miles away, while a magnitude 7 mainshock may have aftershocks as far as 30 to 50 miles away.

M6.0 - South Napa Earthquake

VIII DYFI? | IX ShakeMap | RED PAGER

Location

Data Source NC[1]

38.215°N 122.312°W depth=11.3 km (7.0 mi)

View interactive map

Time

2014-08-24 10:20:44 (UTC)
2014-08-24 03:20:44 (UTC-07:00) in your timezone
Times in other timezones

Nearby Cities

6km (4mi) NW of American Canyon, California
9km (6mi) SSW of Napa, California
13km (8mi) NNW of Vallejo, California
15km (9mi) ESE of Sonoma, California
82km (51mi) WSW of Sacramento, California

The earthquake lies within a 70-km-wide (44 miles) set of major faults of the San Andreas Fault system that forms the boundary between the Pacific and North American tectonic plates. The persistent northwestward movement of the Pacific plate relative to North America primarily causes right-lateral slip across the major faults, but also causes deformation between the major faults. The ongoing complex deformation field is revealed by modern geodetic surveys and earthquake patterns as well as the regional geologic structure. The earthquake is located at the eastern shore of San Pablo Bay between two major active fault systems: the Hayward-Rodgers Creek Fault system on the west and the Concord-Green Valley Fault system on the east. The earthquake occurred near the well-known West Napa Fault, and the less well known Carneros-Franklin Faults, which juxtapose different suites of rocks. Although there are several faults in the region of the earthquake, only the West Napa Fault is known to have displaced Holocene-age sediment — which is positive evidence of surface fault rupture in the last 11,000 years.

Focal Mechanism

Finite Fault

Waveforms

Latest Earthquakes

Earthquakes

Hazards

Data

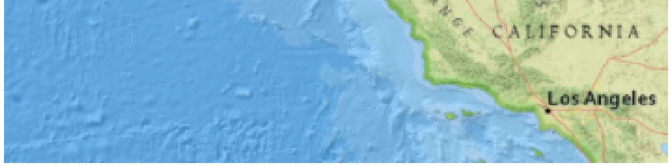
Learn

Monitoring

Research

Search...

Search



38.215°N 122.312°W depth=11.3 km (7.0 mi)

View interactive map

The earthquake lies within a 70-km-wide (44 miles) set of major faults of the San Andreas Fault system that forms the boundary between the Pacific and North American tectonic plates. The persistent northwestward movement of the Pacific plate relative to North America primarily causes right-lateral slip across the major faults, but also causes deformation between the major faults. The ongoing complex deformation field is revealed by modern geodetic surveys and earthquake patterns as well as the regional geologic structure. The earthquake is located at the eastern shore of San Pablo Bay between two major active fault systems: the Hayward-Rodgers Creek Fault system on the west and the Concord-Green Valley Fault system on the east. The earthquake occurred near the well-known West Napa Fault, and the less well known Carneros-Franklin Faults, which juxtapose different suites of rocks. Although there are several faults in the region of the earthquake, only the West Napa Fault is known to have displaced Holocene-age sediment — which is positive evidence of surface fault rupture in the last 11,000 years.

Historically, in this region shaking sufficient to seriously damage structures at Mare Island occurred during the M6.8 1868 Hayward Fault earthquake, the M7.8 1906 San Andreas Fault earthquake, and particularly during the M6.3 1898 Mare Island earthquake. The 1898 earthquake may have occurred about 20 km (12 miles) to the northwest on the southern Rodgers Creek Fault. Even larger nearby events than the 1898 earthquake can be expected in the future. In addition, the epicentral region of this earthquake is depicted on the USGS National Seismic Hazard Maps to have a high probability of strong shaking in the future.

The earthquake is located between two major, largely strike-slip fault systems. The Hayward-Rodgers Creek Fault system, which is approximately 7 km (4 miles) west of the site, generated damaging earthquakes in 1868 and probably in 1898. The Concord-Green Valley Fault system, which is 12 km (7 miles) east of the site, produced a M5.5 earthquake in 1954; while it has not generated a large historical event, there is strong evidence for recent pre-historic activity. The 1999 Working Group on California Earthquake Probabilities (WG99, 1999) concluded that the Hayward-Rodgers Creek Fault system has a 32 percent probability of generating a large earthquake (M6.7 to 7.4) by the year 2030, and the Concord-Green Valley Fault system has a 6 percent chance of generating a large earthquake (M≥6.7) in the same time period.

The earthquake occurred near the north shore of San Pablo Bay. The bayshore areas in the San Francisco Bay region are underlain by landfill and bay mud and have experienced disproportionately greater damage during historic earthquakes. Such damage is caused by soil failure in the fills and amplification of ground shaking by the soft bay mud.

One person killed and at least 208 people injured, 150 buildings severely damaged and 1,000 buildings moderately damaged in Napa County. At least 49 people injured, 10 buildings severely damaged and 34 buildings moderately damaged in Solano County. Minor damage to several roads and several water main and gas line breaks in Napa and Solano Counties. Electricity and water services disrupted in Napa, Solano and Sonoma Counties. Six fires occurred in Napa County destroying at least 4 buildings. At least 8 km of surface faulting with at least 46 cm of right-lateral and 15 cm vertical displacements observed. The total economic loss estimated at 400 million U.S. dollars. Felt (VIII) at Napa; (VII) at American Canyon, Vallejo and Yountville; (VI) at Crockett, Deer Park, Glen Ellen, Port Costa, Rodeo and Sonoma. Felt in many parts of central and northern California from Arcata to Bakersfield. Felt (II) at Reno, Nevada. Also felt at Carson City, Glenbrook, Incline Village, Minden and Sparks.

For More Information

- Additional earthquake information for California
- Aftershock Warning
- South Napa, USA Earthquake Clearinghouse
- Photos of Damage and Surface Features
- Earthquake Summary Poster

USGS goals in OEF R&D

- Broaden scope to all of USGS and globe,
- Modernize and test calculation methods,
- Tailor products and product delivery to meet identified user needs,
- Improve coordination between USGS, scientific partners, and various user groups,
- Advance the science in earthquake forecasting with pathway to using best-available methods in operations,
- Integrate OEF into seismic network and product delivery systems,
- Protect the ability of research staff to do research,
- Right-size OEF R&D within the Earthquake Hazards Program.

Guidance from advisory committees

- Proceed with broadening geographic scope of aftershock forecasting, and improving communication of aftershock forecasts.
- Further efforts should be guided by identified user needs.
- NEPEC met two weeks ago, preparing report on OEF.
- NEPEC recommendations to be considered by our program advisory committee in February.

USGS Powell Center Meetings on OEF

1. **Potential Uses of OEF (March 16-19, 2015)**
2. Best Science for OEF (Oct 19-22, 2015)
3. Operationalization Challenges for OEF (future?)
4. OEF Testing and Verification (future?)

Project Goal - to deploy at least a prototype OEF system for California (although developments will be applicable elsewhere)

Workshop involved discussions among a variety of potential users and model developers in an effort to identify potential uses of OEF; also examined lessons learned from recent earthquakes and best practices regarding effective communication

SRL submission:

The Potential Uses of Operational Earthquake Forecasting (A Workshop Report)

by Field, Jordan, Jones, Michael, Blanpied, & the other workshop participants…

USGS science for a changing world

1. Potential Uses of OEF (March 16-19, 2015)

Uses/Users Discussed:

- **Public preparedness**
- **Official Advisory Councils**
- **Emergency Management**
    - CalOES
    - School Systems
    - Caltrans
    - Utility Companies
    - Hospitals
- **Post-Earthquake Building Inspection/Tagging**
- **Zoning and Building Codes**
- **Oil and Natural Gas Regulation**
- **Insurance Industry and Capital Markets**
- **Others**

Updating the Reasenberg & Jones aftershock forecast method

Algorithm Improvements:

1) Expand beyond California: implement nation-wide, and develop capability for global earthquakes when needed.
2) Determine generic aftershock parameters for global tectonic regions, and additional states/regions within the US.
3) Model the time-dependent magnitude of completeness of the catalog when fitting sequence-specific parameters.
4) Sequence-specific productivity only, to avoid over-fitting, unless other sequence-specific parameter are strongly required.
5) Improve methods to combine generic and sequence-specific parameters.

Implementation Improvements:

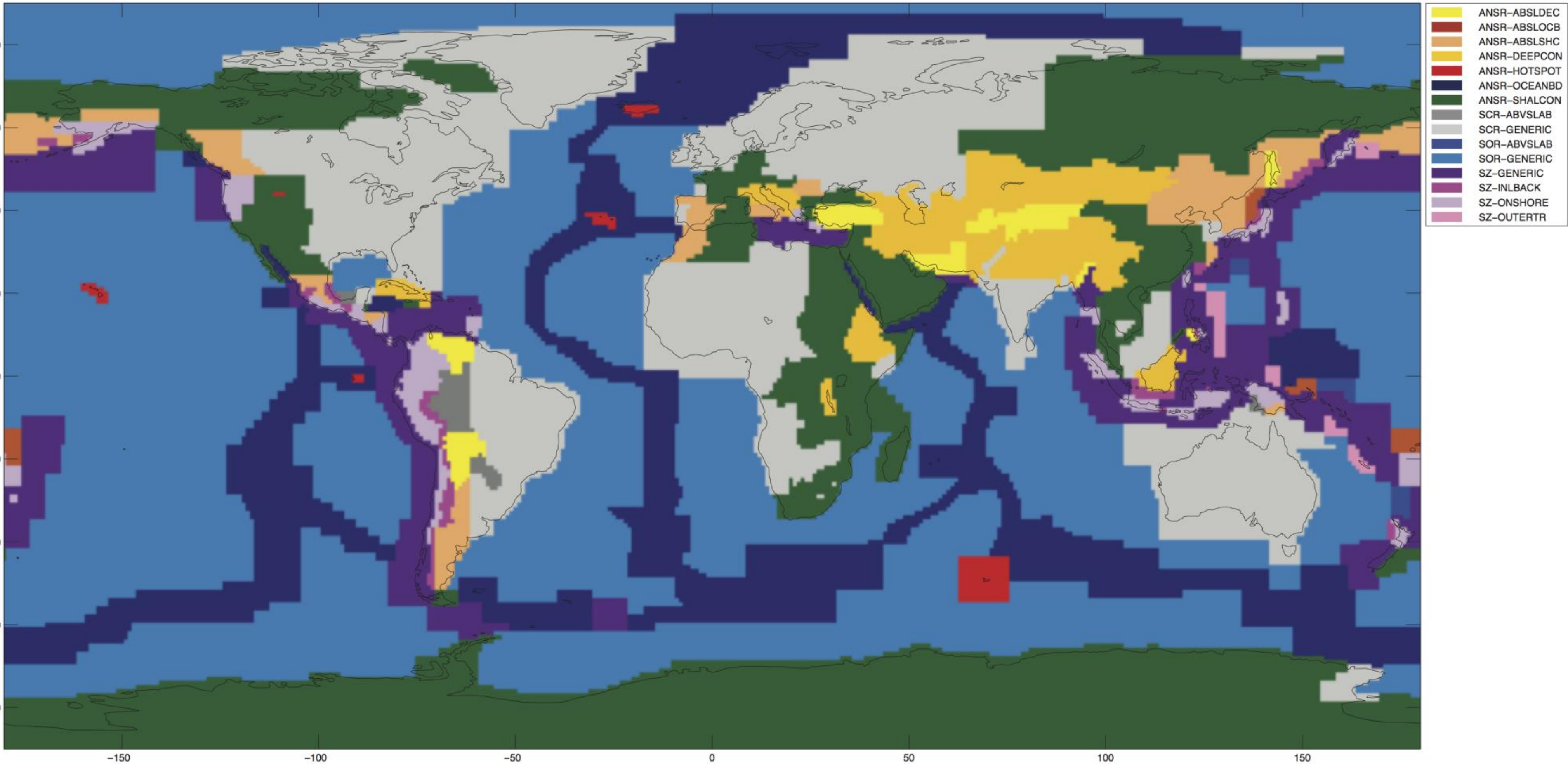
1) Implement in a modern computer language (Java).
2) Integrate into NEIC operations, interface with Comcat/PDL.

Messaging Improvements:

1) Work with users (e.g. emergency managers) and social scientists to craft new message templates for US earthquakes.
2) Experiences from Nepal will inform decisions about whether/how to issue forecasts following international earthquakes.

USGS
science for a changing world

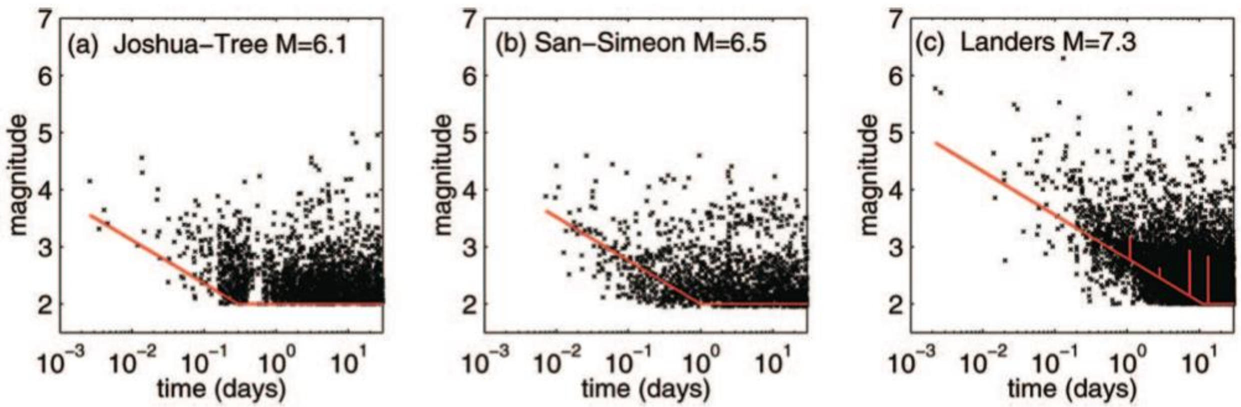
Generic R&J model parameters determined for Garcia tectonic regions



USGS
science for a changing world

Sequence-specific Parameters: *Determine sequence-specific parameters using the aftershock sequence so far.*

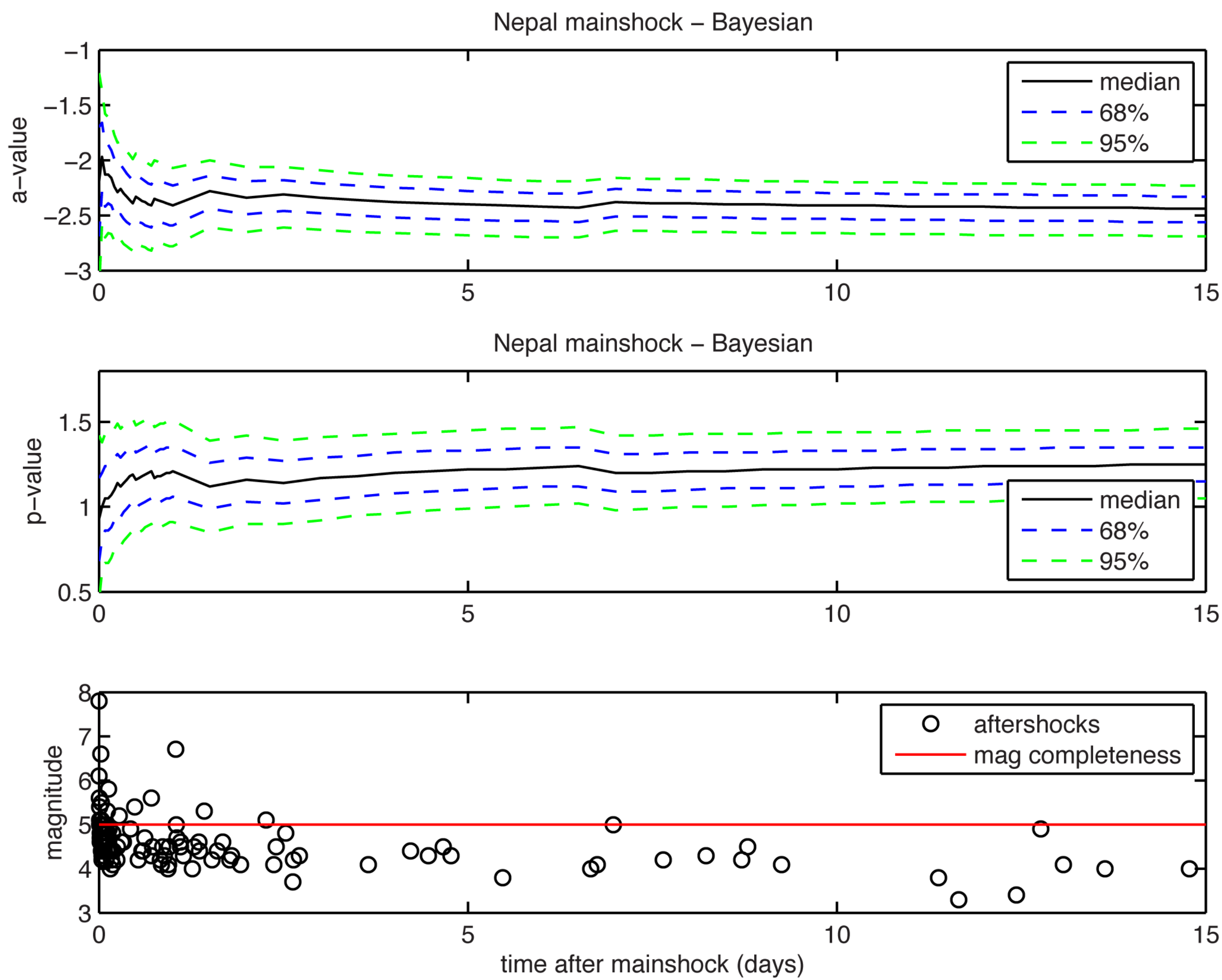
- Minimum magnitude from time-dependent magnitude of completeness following mainshock.
- Helmstetter et al. (BSSA, 2006) determined for California



- Generalized form:

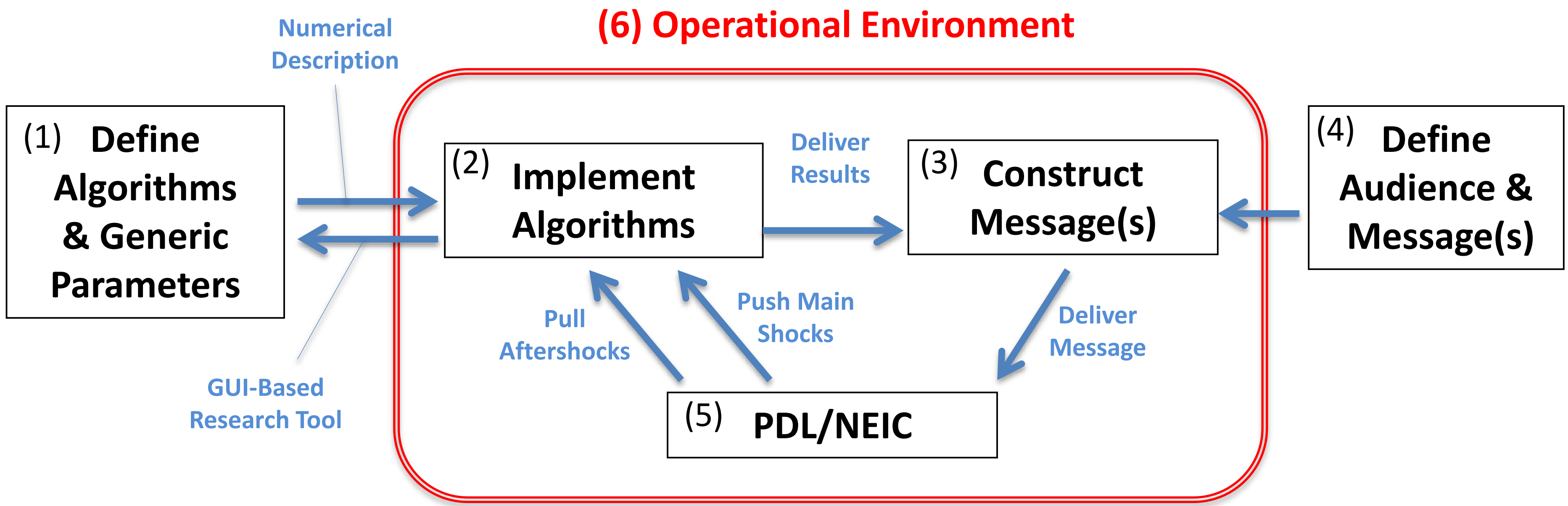
$$M_c(t, M_m) = M_m - G - H log_{10}(t + c), \text{ and } M_c \geq M_{cat}$$

- G & H parameters depend on catalog, Mm=mainshock magnitude, Mcat=background completeness level



Nepal mainshock – Bayesian
a–value
median
68%
95%
Nepal mainshock – Bayesian
p–value
median
68%
95%
magnitude
aftershocks
mag completeness
time after mainshock (days)

Implementation:



Current status:

1. Algorithms defined. Finalizing global parameters, working on regional parameters.
2. GUI-based research tool developed, can serve as prototype for operational system.

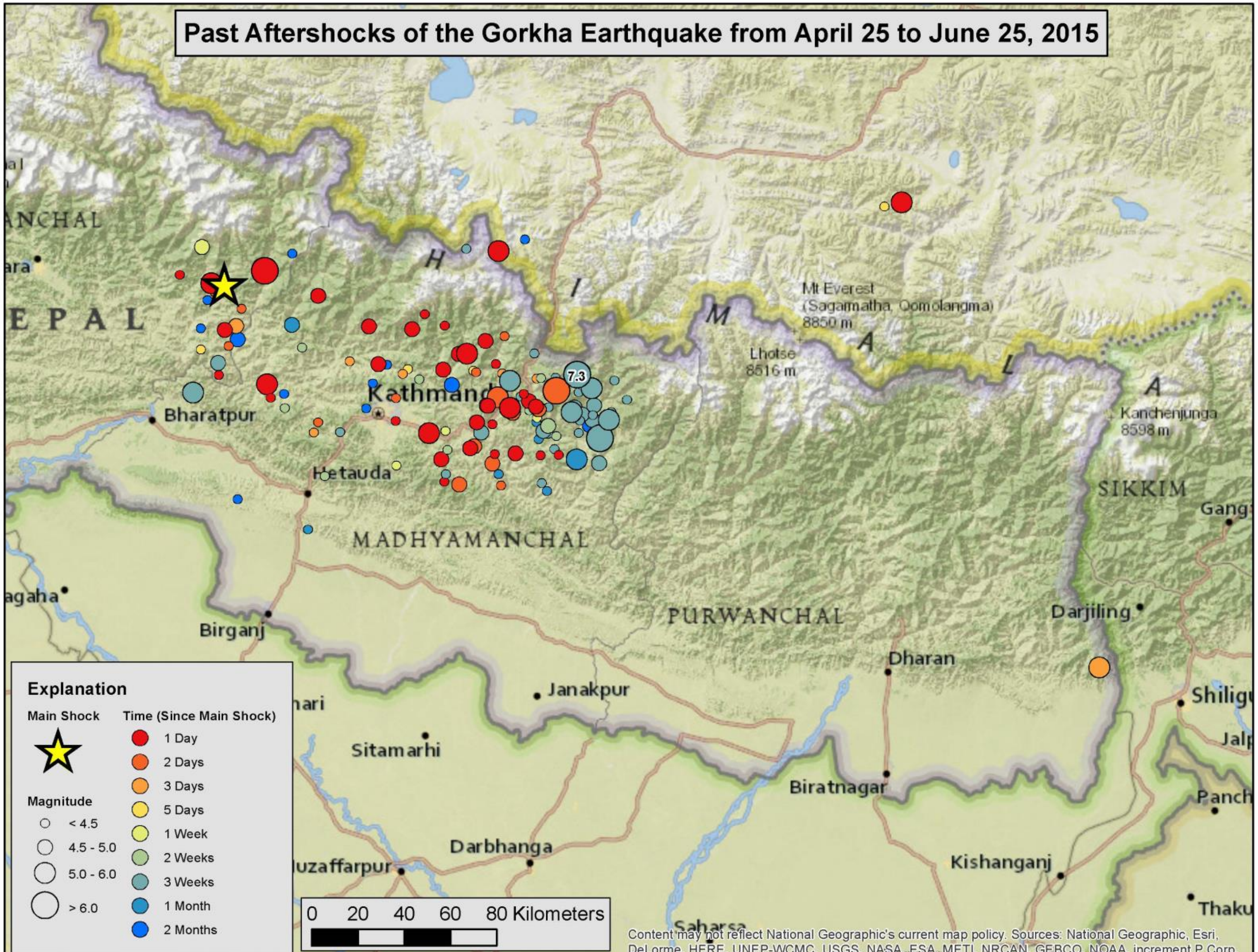
3&4. Working with potential users and social scientists to construct message templates.

5. Developing interface with Comcat/PDL.
6. Need a path forward to operationalization at NEIC.

USGS science for a changing world

USGS Aftershock Advisories for the Gorkha Earthquake

~9000 fatalities, ~23,000 injuries, ~$5B in damage (25% of GDP)



USGS Aftershock Advisories for the Gorkha Earthquake

Impetus: Request from the USAID Office of US Foreign Disaster Assistance to support their Disaster Assistance Response Team (DART) which coordinated US Government disaster response, including search and rescue, with the Government of Nepal.

Due to the possible utility of the forecasts to people in the region and other response teams, the USGS released these forecasts publicly through the USGS Earthquake Program web site.

Incorporated lessons learned from Christchurch.

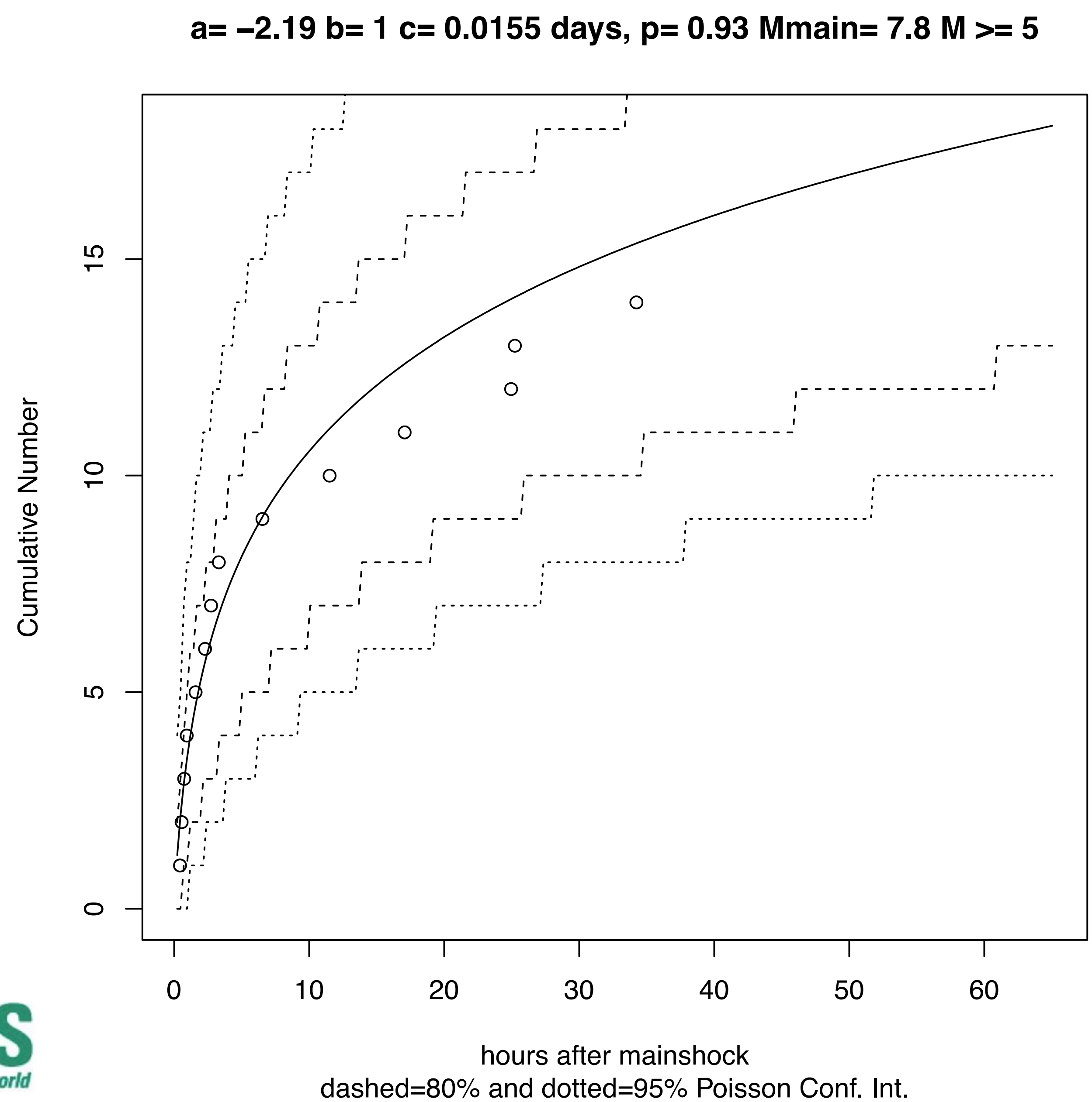
Coordinated with the US Embassy in Kathmandu.

Tried, but failed to be able, to coordinate with National Society for Earthquake Technology and the Nepal National Seismological Centre.

The Italian OEF program also calculated aftershock probabilities but did not release them.

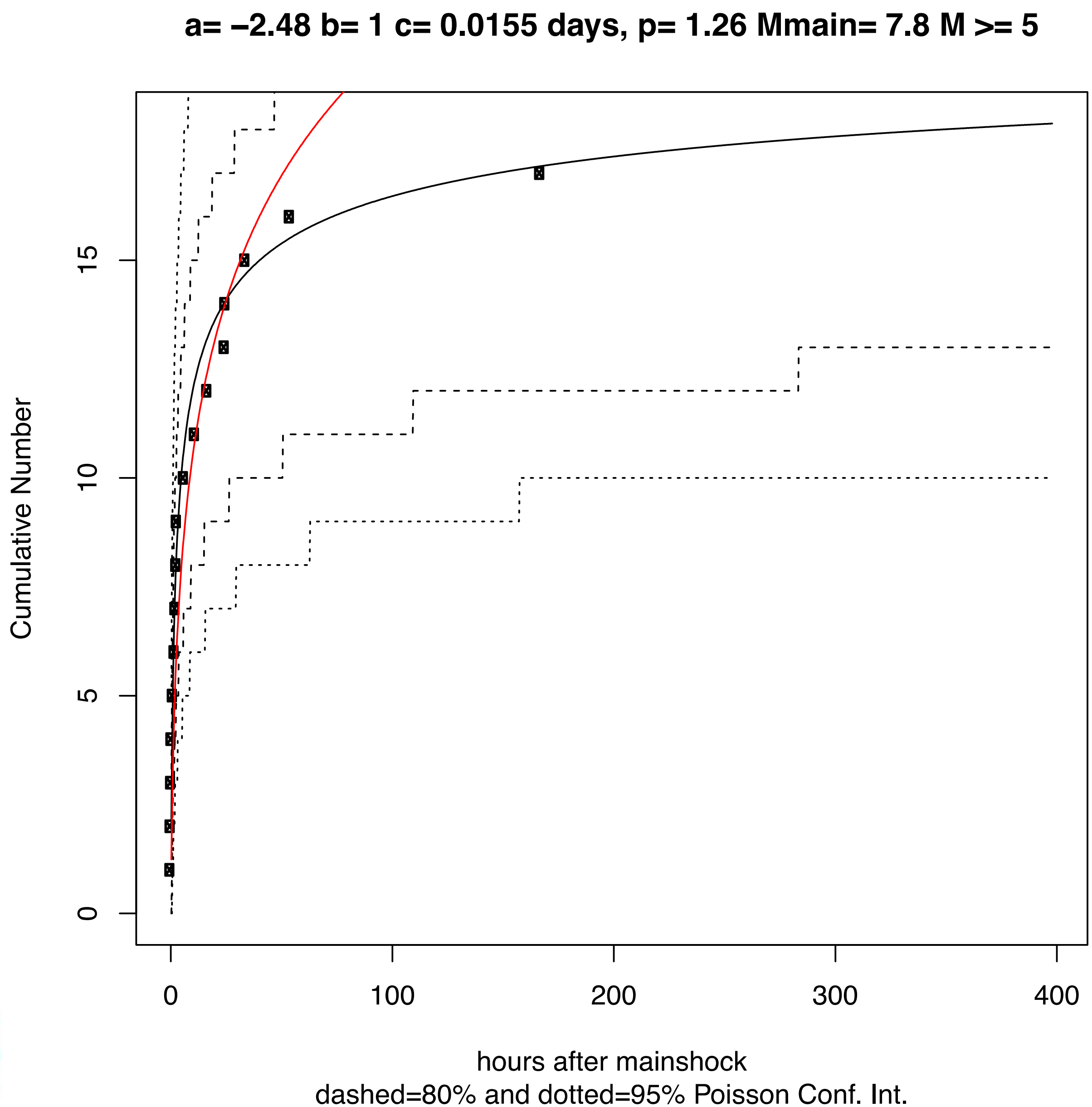
USGS
science for a changing world

First 70 hours of Aftershock Sequence with Generic Forecast Model



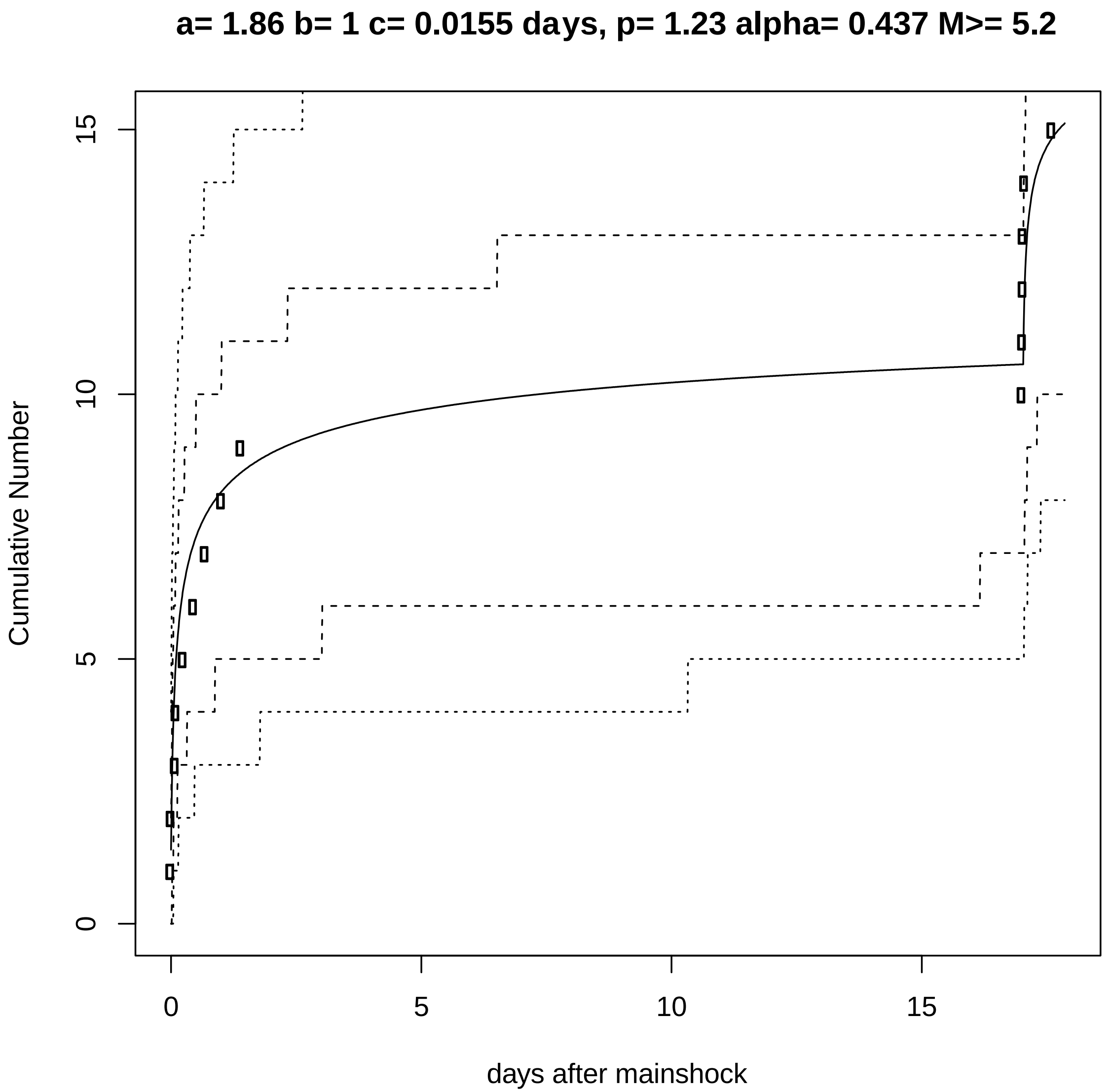
First 400 hours of Aftershock Sequence with Updated Forecast Model

(original model in red)

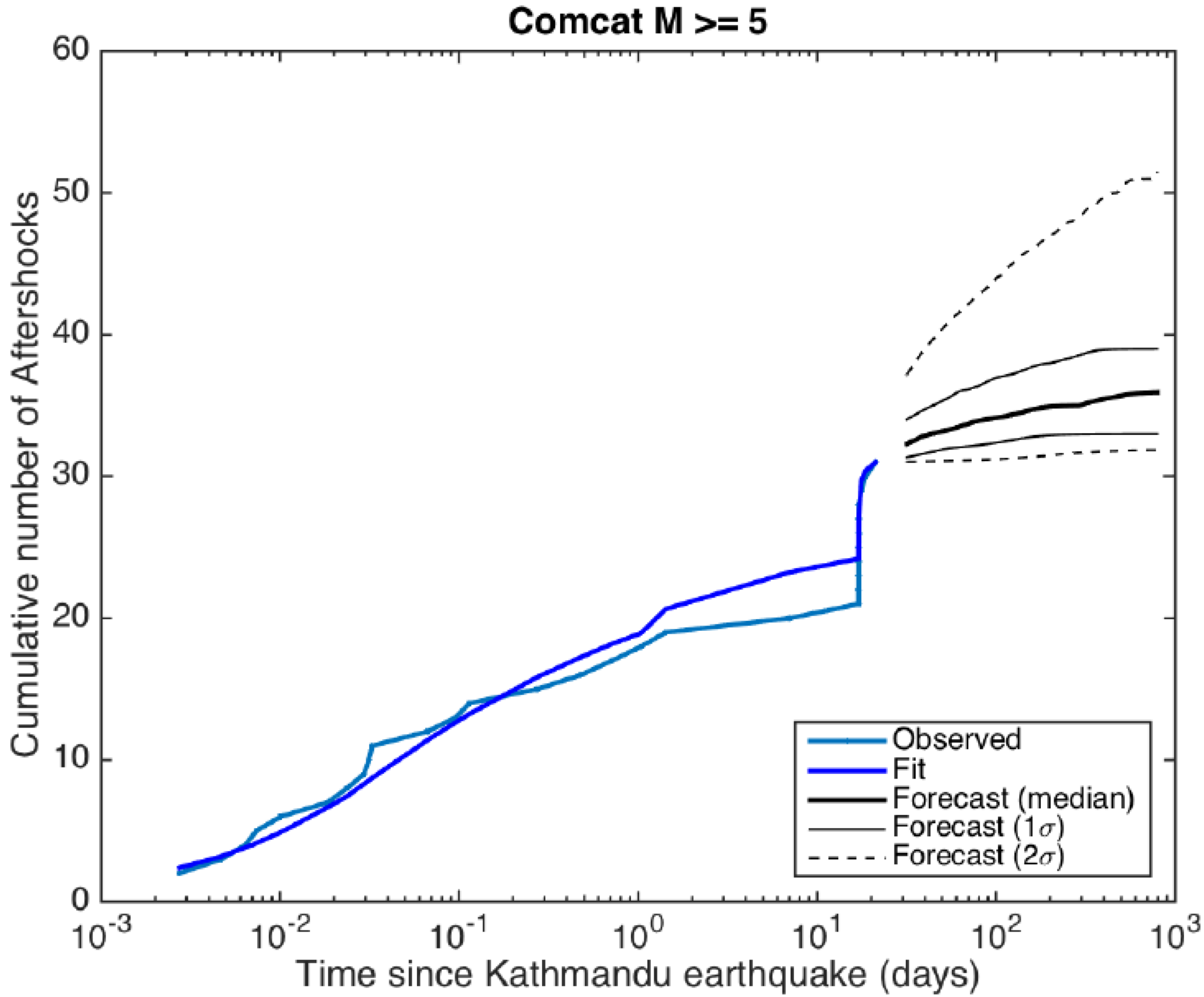


USGS science for a changing world

Aftershock Sequence after M7.3 aftershock
Fit two a 2-source RJ89 model



ETAS Model
Nicholas
Van der Elst




```
Forecast generated 26-May-2015 09:04:53

ETAS parameters: (mu:0.00) k:0.003 c:0.01 (alpha:1.00) p:1.29
(b:1.00) Mc:5.0 activeMmin:2.0 nsims:100000
() if parameter is at constraint boundary
```

USGS
science for a changing world

Characterizing the Likelihood of Rare Large Aftershocks

Time Window for Analysis	Magnitude (M) range of aftershocks considered	Range of Expected Number of Aftershocks (95% confidence)	Probability of one or more aftershocks	Probability of no aftershock
1 Week starting on May 08, 2015 to the end of May 14, 2015	M5.0 to M6.0	0 - 2	37%	63%
	M6.0 to M7.0	0 - 1	5%	95%
	M7.0 to M7.8	0 - 0	0.4%	99.6%
	M ≥ 7.8	0 - 0	0.08%	99.92%
1 Month starting on May 08, 2015 to the end of June 08, 2015	M5.0 to M6.0	0 - 4	70%	30%
	M6.0 to M7.0	0 - 1	11%	89%
	M7.0 to M7.8	0 - 0	1%	99%
	M ≥ 7.8	0 - 0	0.2%	99.8%
1 Year starting at May 08, 2015 to the end of May 07, 2016	M5.0 to M6.0	0 - 6	93%	7%
	M6.0 to M7.0	0 - 2	23%	77%
	M7.0 to M7.8	0 - 0	2%	98%
	M ≥ 7.8	0 - 0	0.5%	99.5%

USGS Aftershock Advisories for the Gorkha Earthquake

Communications Issues:

Basic problem: simply communicating a distribution that varies with time, magnitude, and location.

Additional problem: language issues, distance, societal differences.

Multiple Time Windows:

- Aftershock probabilities are useful over a range of time scales.
- Multiple time windows can confuse the forecast.
- Should they all start at the current time or abut each other.
- Solution was focusing on the shortest time window in the advisory and including more info in the "statistical analysis."
- What should the shortest and longest intervals be?

Comparing the aftershock hazard to background hazard was difficult due to lack of access to a hazard model for Nepal.

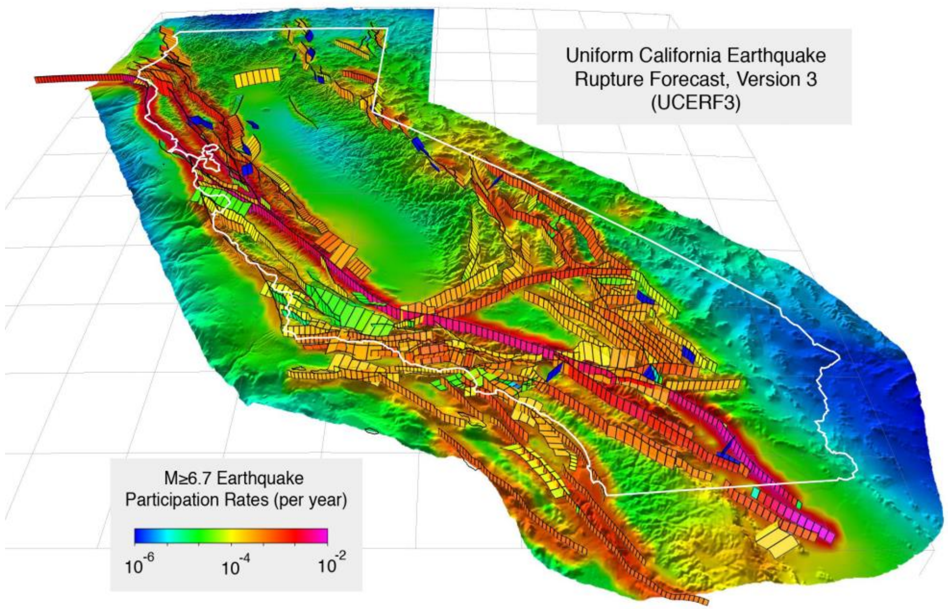
USGS
science for a changing world

UCERF3-ETAS
Including Spatiotemporal Clustering for a California Operational Earthquake Forecast (OEF)

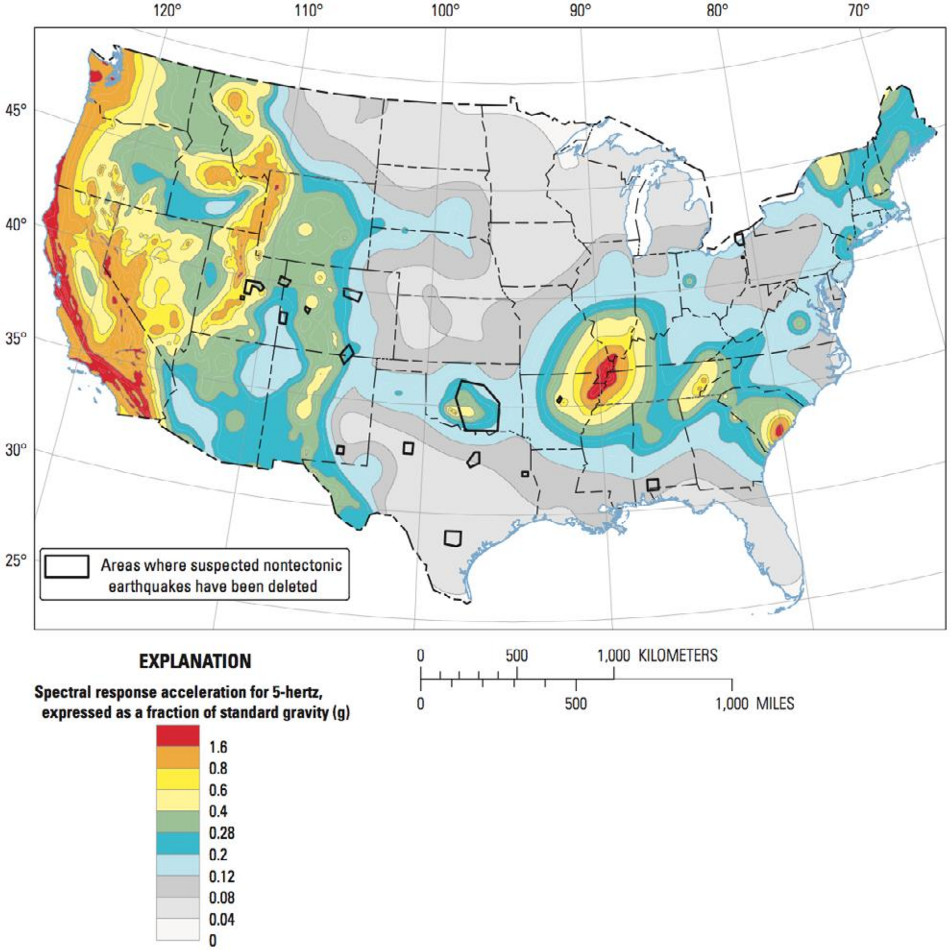
By the ongoing Working Group on California Earthquake Probabilities (WGCEP)

Field, E. H. , M. T. Page, T. H. Jordan, J. R. Arrowsmith, G. P. Biasi, P. Bird, T. E. Dawson, K. R. Felzer, D. D. Jackson, K. M. Johnson, C. Madden, A. J. Michael, K. R. Milner, T. Parsons, P. M. Powers, B. E. Shaw, W. R. Thatcher, R. J. Weldon, and Y. Zen

***OEF additions**: M. Blanpied, J. Hardebeck, L. Jones, W. Marzocchi, K. Porter, D. Trugman, M. Werner, N. van der Elst*



2014 NSHM (July 2014 release)



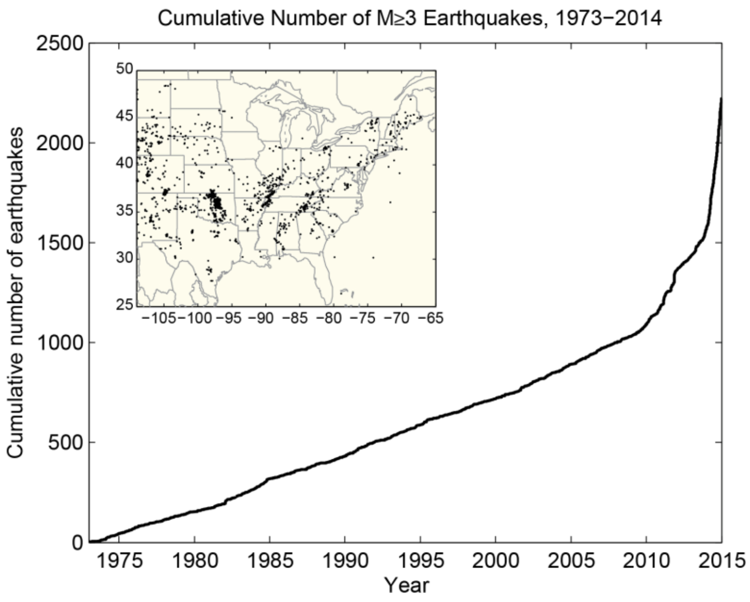
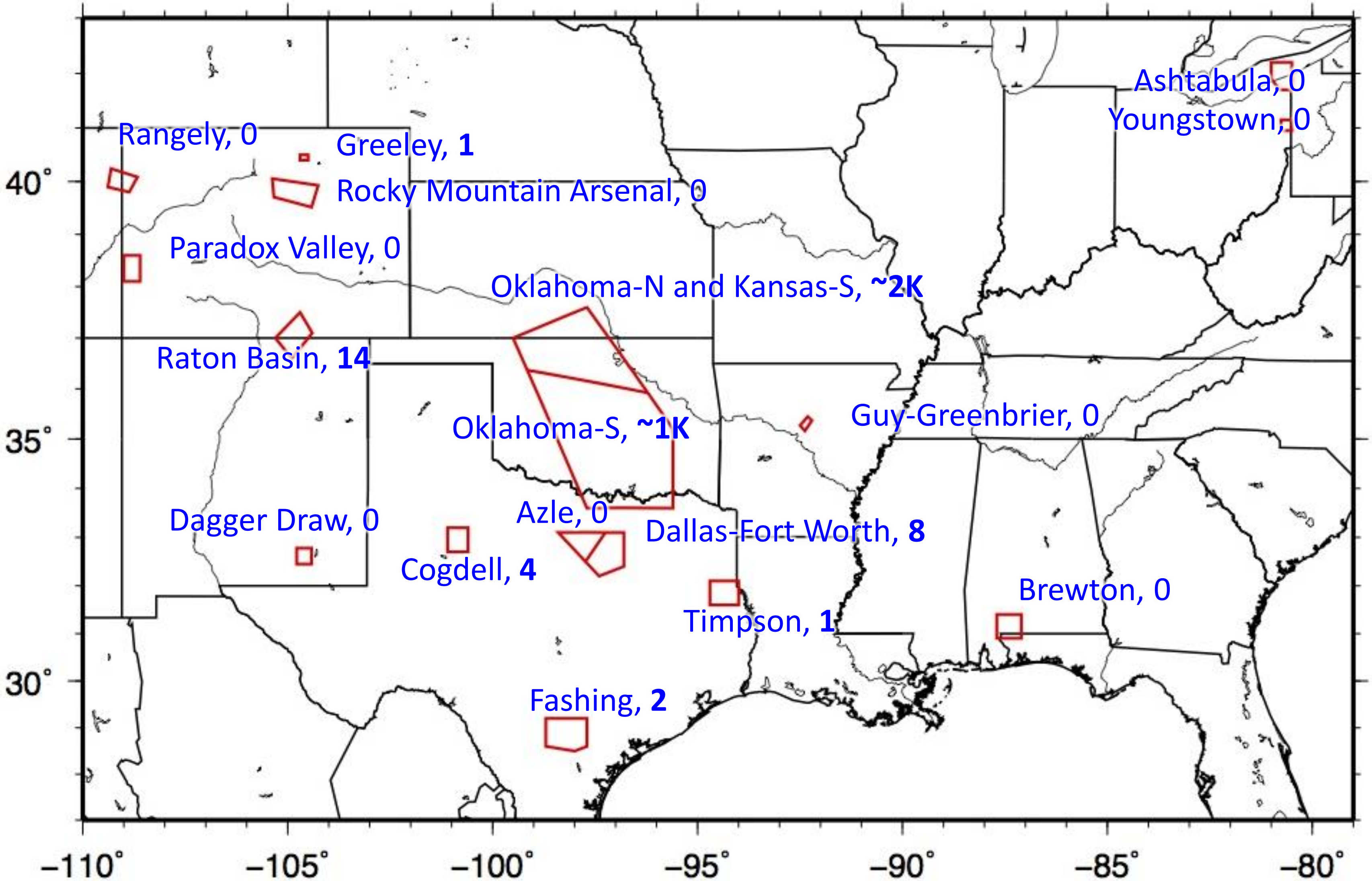


Figure courtesy W. Ellsworth

17 Zones, Potentially Induced Seismicity

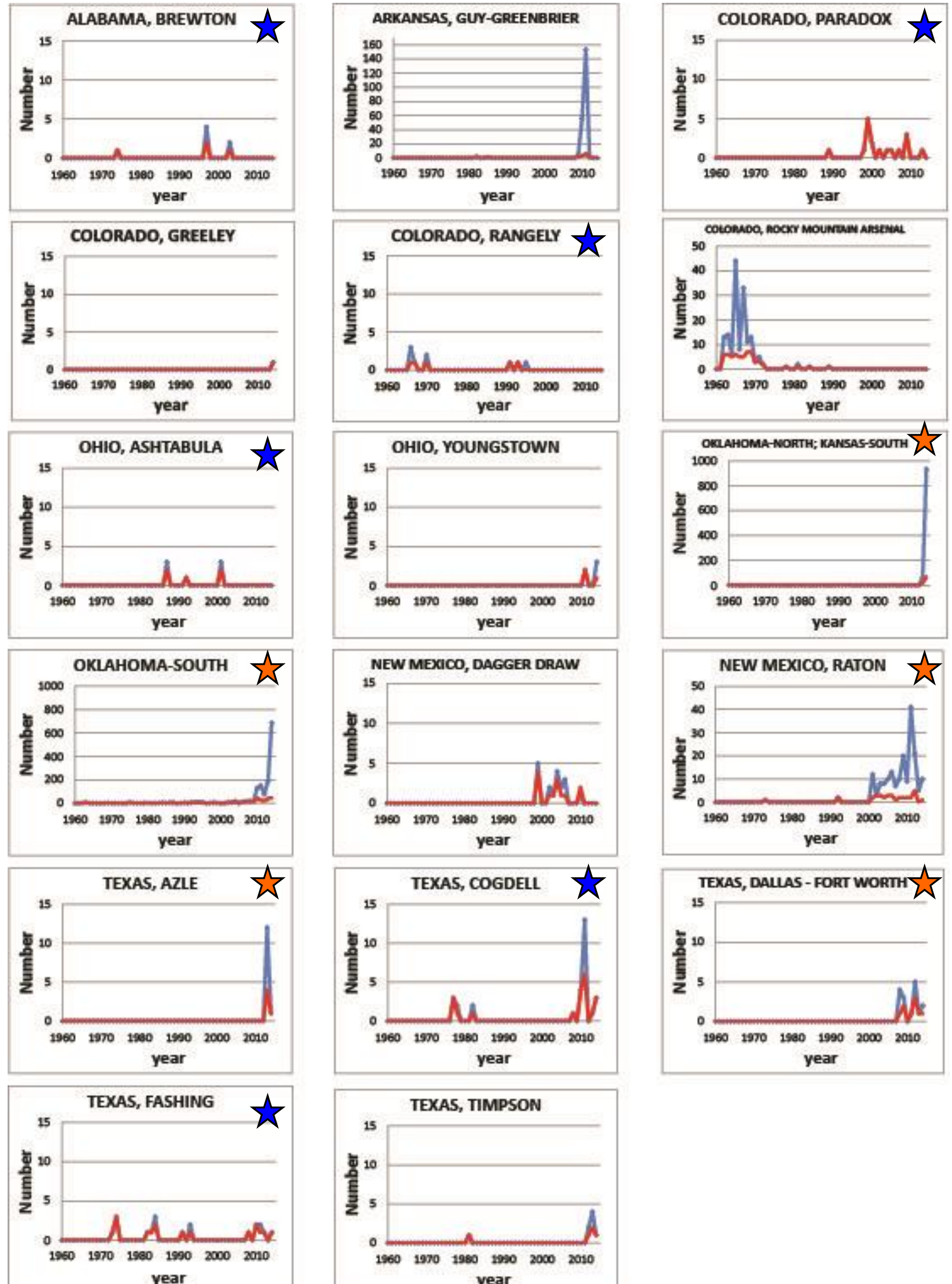
Number of M2.7+ earthquakes for the 12-month catalog (May 2014-April 2015)



science for a changing world

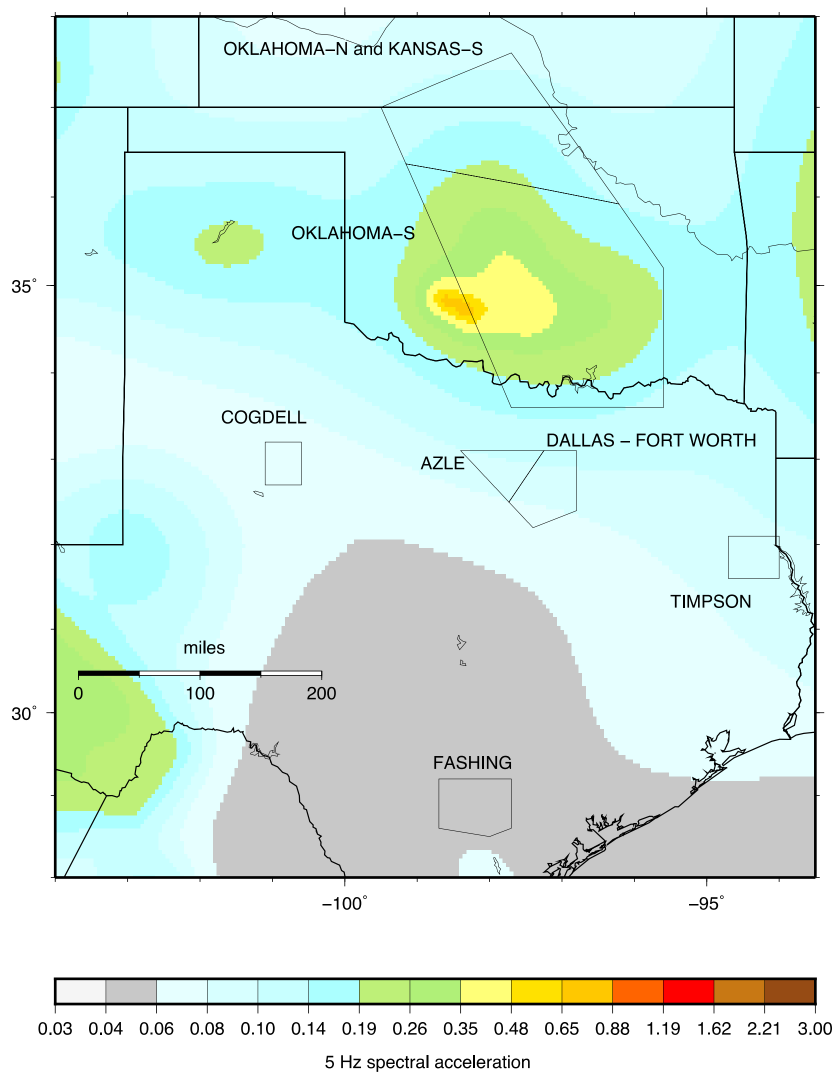
Time histories

The 17 sites have different behaviors: At Brewton, Paradox, Rangely, Astabula, Cogdell, and Fashing (blue stars) the induced earthquakes continue for longer time periods. Increasing seismicity rates in Oklahoma, Raton, Azle, and Dallas (orange stars.



USGS science for a changing world

2014 NSHM.
No induced earthquakes



One model from 2015-OFR.
Including induced earthquakes