Integrated Strategies for Enhanced Rapid Earthquake Shaking, Ground Failure, & Impact Estimation Employing Remotely Sensed & Ground Truth Constraints

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Stony Brook University

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Stanford University

12NCEE Meeting, Salt Lake City

June 29, 2022

← Latest Earthquakes

Overview

Interactive Map

Regional Information

Impact

Felt Report - Tell Us!

Did You Feel It?

ShakeMap

PAGER

Ground Failure

Technical

Origin

Moment Tensor

Waveforms

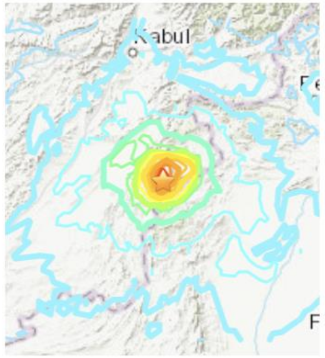
Download Event KML

View Nearby Seismicity

M 5.9 - 46 km SW of Khōst, Afghanistan

2022-06-21 20:54:36 (UTC) | 33.092°N 69.514°E | 10.0 km depth

Interactive Map



Contributed by US [2]

Regional Information

Contributed by US [2]

Felt Report - Tell Us!

0 0 0 0 7 3

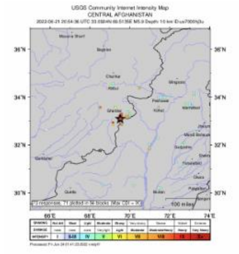
Responses

Contribute to citizen science. Please tell us about your experience.

Citizen Scientist Contributions

Did You Feel It?

IX

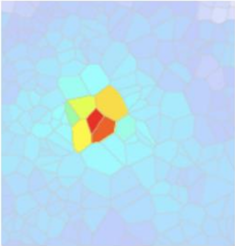


Community Internet Intensity Map

Contributed by US [2]

ShakeMap

IX

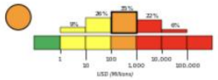


Estimated Intensity Map

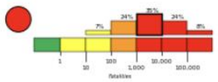
Contributed by US [2]

PAGER

RED



Estimated Economic Losses



Estimated Fatalities

Contributed by US [2]

Ground Failure

Landslide Estimate

Significant area affected

Limited population exposed

Liquefaction Estimate

Little or no area affected

Little or no population exposed

Contributed by US [2]

Origin

Review Status

REVIEWED

Magnitude

5.9 mwb

Depth

10.0 km

Time

2022-06-21 20:54:36 UTC

Contributed by US [2]

Moment Tensor

Fault Plane Solution

Contributed by US [2]

View Nearby Seismicity

Time Range

± Three Weeks

Search Radius

250.0 km

Magnitude Range

≥ 2.0

ANSS Comcat

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Earthquake Shaking **Yellow Alert**

GSN ANSS USAID FROM THE AMERICAN PEOPLE

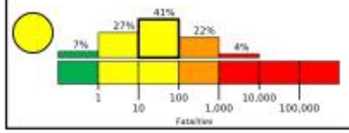
M 5.9, 46 km SW of Khst, Afghanistan

PAGER Version 2

Origin Time: 2022-06-21 20:54:36 UTC (Wed 01:24:36 local)
Location: 33.0924° N 69.5135° E Depth: 10.0 km

Created: 58 minutes, 54 seconds after earthquake

Estimated Fatalities



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Green alert for economic losses. There is a low likelihood of damage.

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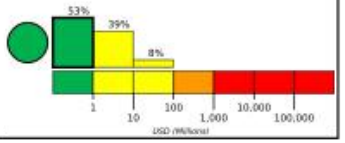


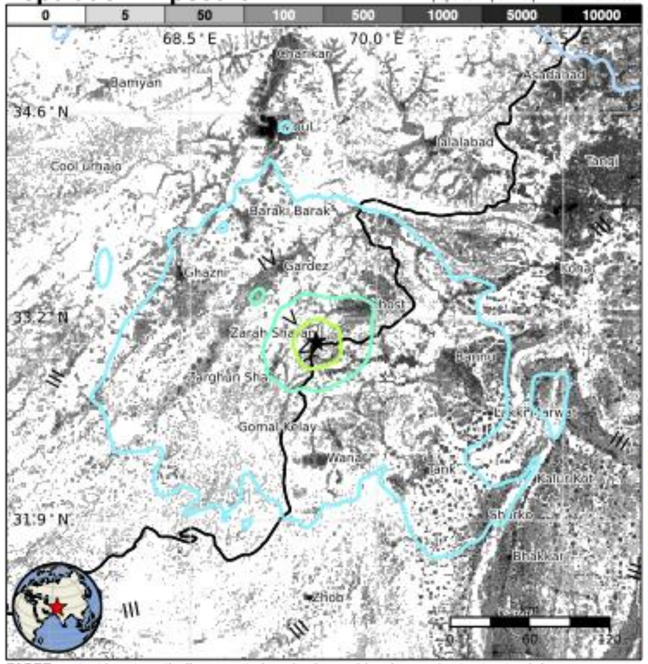
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k=x1000)		--*	35,970k*	13,517k	884k	119k	7k	0	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	None	None	None	V. Light	Light	Moderate	Mod./Heavy	Heavy	V. Heavy
	Vulnerable Structures	None	None	None	Light	Moderate	Mod./Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per 1 sq. km from Landscan



Structures

Overall, the population in this region resides in structures that are extremely vulnerable to earthquake shaking, though some resistant structures exist. The predominant vulnerable building types are adobe block and informal (metal, timber, GI etc.) construction.

Historical Earthquakes

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
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1974-12-28	378	6.2	VIII(6k)	5k

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
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VI	Ster Giyan	<1k
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VI	Nikeh	<1k
VI	Dwah Manday	<1k
V	Urgun	<1k
IV	**Gardez**	**104k**
IV	**Ghazni**	**141k**
IV	**Jalalabad**	**200k**
III	**Kabul**	**3,044k**
III	Peshawar	1,219k

bold cities appear on map. (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
https://earthquake.usgs.gov/earthquakes/eventpage/us7000hj3u#pager

Event ID: us7000hj3u

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Earthquake Shaking **Red Alert**

GSN ANSS USAID FROM THE AMERICAN PEOPLE

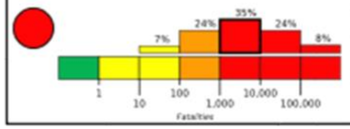
M 5.9, 46 km SW of Khst, Afghanistan

PAGER Version 5

Origin Time: 2022-06-21 20:54:36 UTC (Wed 01:24:36 local)
Location: 33.0924° N 69.5135° E Depth: 10.0 km

Created: 2 days, 17 hours after earthquake

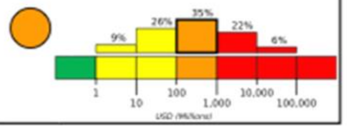
Estimated Fatalities



Red alert for shaking-related fatalities. High casualties are probable and the disaster is likely widespread. Past events with this alert level have required a national or international level response.

Orange alert for economic losses. Significant damage is likely. Estimated economic losses are 0-4% GDP of Afghanistan.

Estimated Economic Losses



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ESTIMATED POPULATION EXPOSURE (k=x1000)		--*	9,181k*	24,327k	1,490k	531k	274k	55k	17k	0
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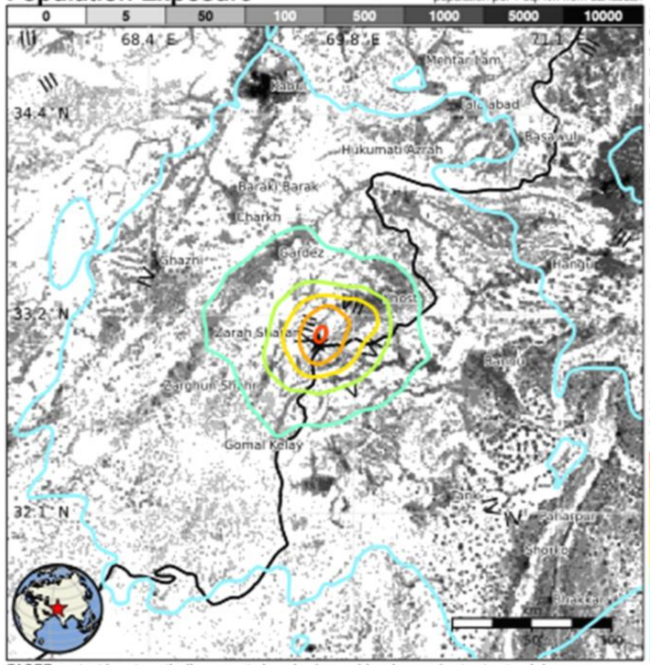

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VII	Ster Giyan	<1k
VII	Nikeh	<1k
VI	Shaykh Amir Kelay	<1k
V	**Gardez**	**104k**
IV	**Ghazni**	**141k**
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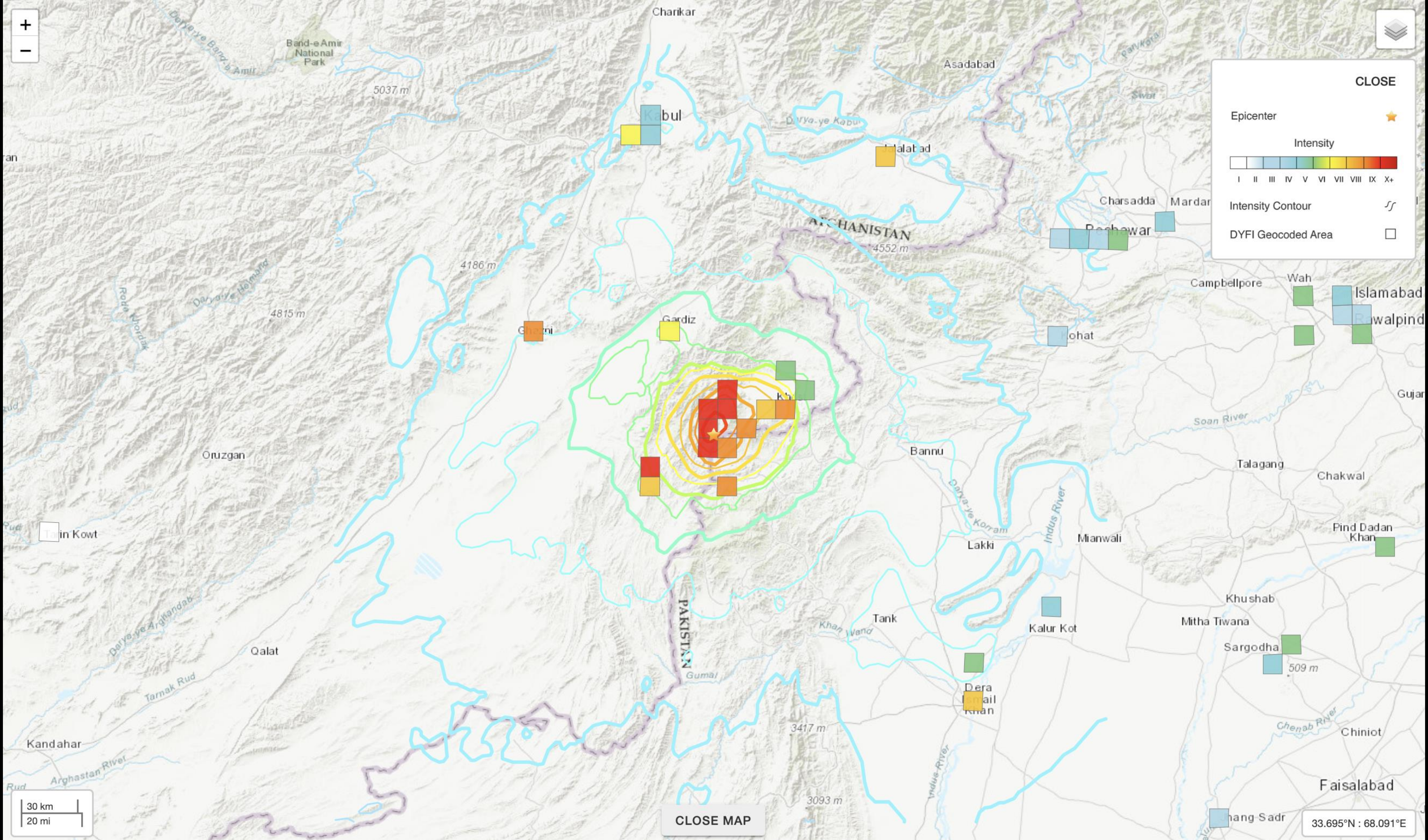
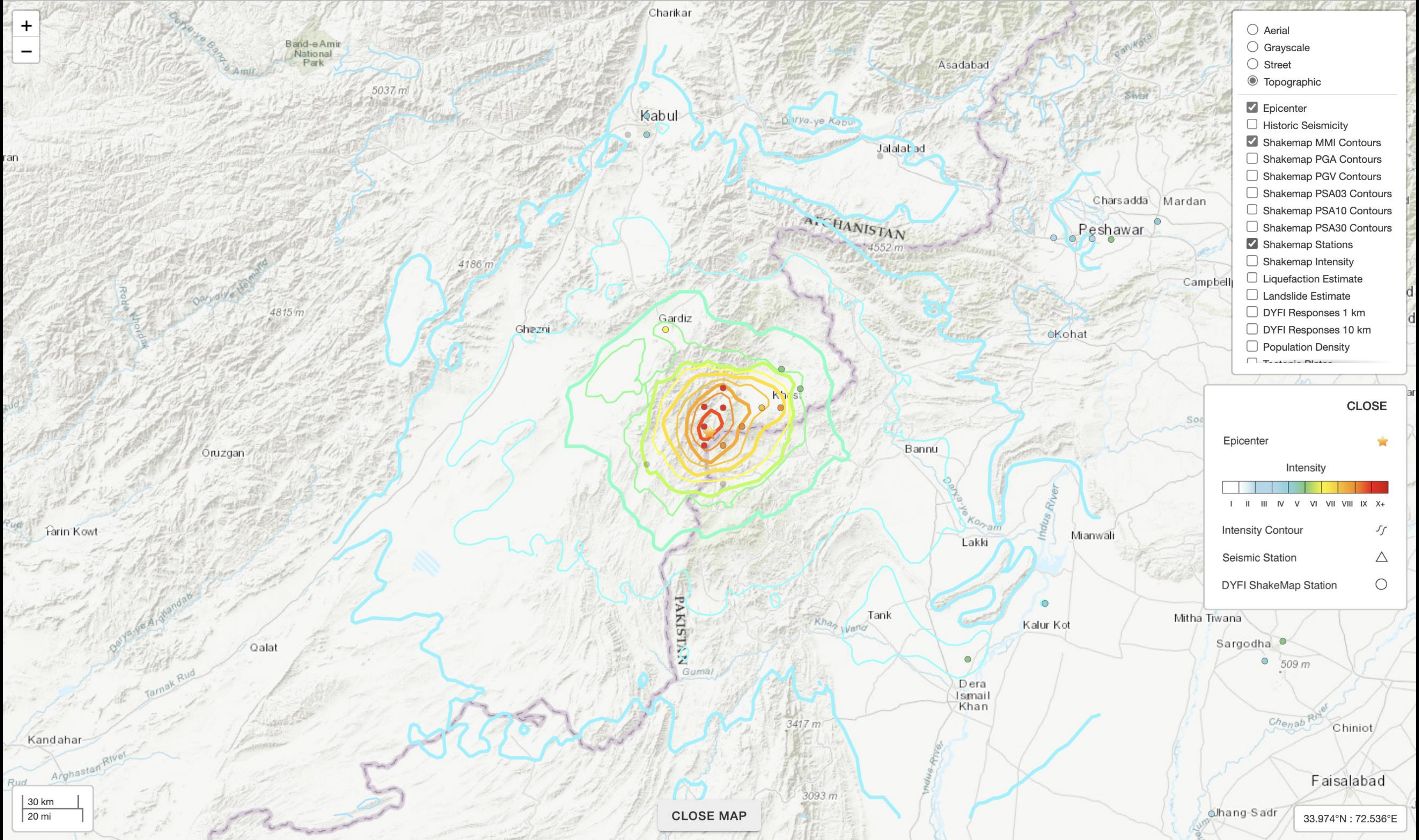
https://earthquake.usgs.gov/earthquakes/eventpage/us7000hj3u#pager

Event ID: us7000hj3u



Charikar
Band-e Amir National Park
5037 m
Kabul
Jalalabad
Asadabad
Charsadda
Mardan
Peshawar
AFGHANISTAN
4552 m
4186 m
4815 m
Ghazni
Gardiz
Campbellpore
Wah
Islamabad
Rawalpindi
Kohat
Oruzgan
Bannu
Soan River
Talagang
Chakwal
Tarin Kowt
Lakki
Mianwali
Indus River
Pind Dadan Khan
PAKISTAN
Tank
Kalur Kot
Khushab
Mitha Tiwana
Sargodha
509 m
Qalat
Dera Ismail Khan
Tarnak Rud
Gumal
3417 m
Chenab River
Chiniot
Kandahar
Arghastan River
3093 m
Faisalabad
Jhang Sadr
30 km
20 mi
CLOSE MAP
33.695°N : 68.091°E
CLOSE
Epicenter
Intensity
I II III IV V VI VII VIII IX X+
Intensity Contour
DYFI Geocoded Area


Charikar
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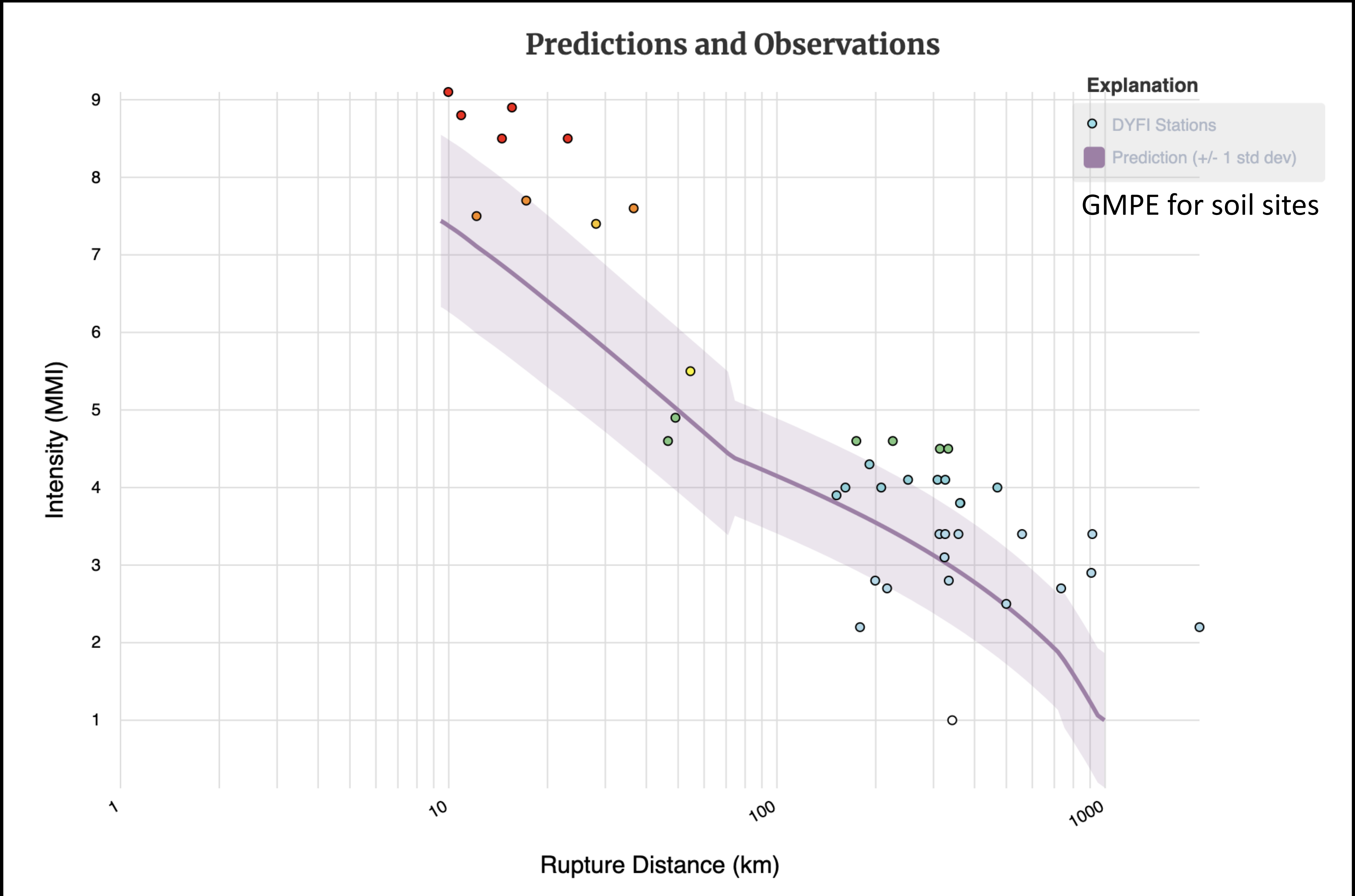
Indus River
Mianwali
Tarin Kowt
Lakki
PAKISTAN
Tank
Kalur Kot
Mitha Tiwana
Qalat
Khan Wand
Gumal
Sargodha
509 m
Dera Ismail Khan
Tarnak Rud
Kandahar
Arghastan River
3417 m
Chenab River
Chiniot
3093 m
Faisalabad
Jhang Sadr
30 km
20 mi
CLOSE MAP
33.974°N : 72.536°E
Aerial
Grayscale
Street
Topographic
Epicenter
Historic Seismicity
Shakemap MMI Contours
Shakemap PGA Contours
Shakemap PGV Contours
Shakemap PSA03 Contours
Shakemap PSA10 Contours
Shakemap PSA30 Contours
Shakemap Stations
Shakemap Intensity
Liquefaction Estimate
Landslide Estimate
DYFI Responses 1 km
DYFI Responses 10 km
Population Density
CLOSE
Epicenter
Intensity
I II III IV V VI VII VIII IX X+
Intensity Contour
Seismic Station
DYFI ShakeMap Station


Predictions and Observations
Explanation
DYFI Stations
Prediction (+/- 1 std dev)
GMPE for soil sites
Intensity (MMI)
9
8
7
6
5
4
3
2
1
1
10
100
1000
Rupture Distance (km)

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Earthquake Shaking Yellow Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

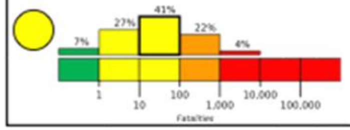
M 5.9, 46 km SW of Khst, Afghanistan

Origin Time: 2022-06-21 20:54:36 UTC (Wed 01:24:36 local)
Location: 33.0924° N 69.5135° E Depth: 10.0 km

PAGER Version 2

Created: 58 minutes, 54 seconds after earthquake

Estimated Fatalities



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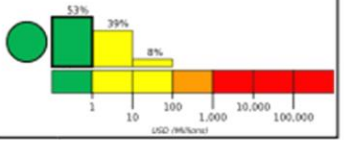

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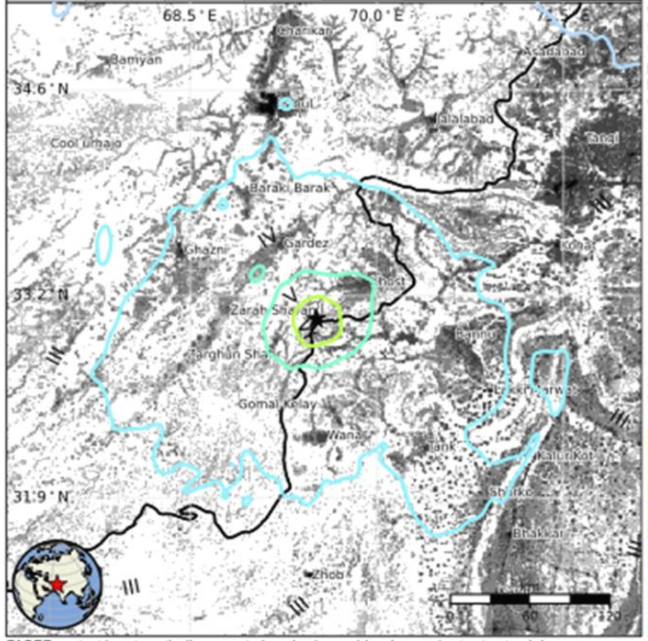
Population Exposure

population per 1 sq. km from Landscan



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https://earthquake.usgs.gov/earthquakes/eventpage/us7000hj3u#pager

Event ID: us7000hj3u

USGS
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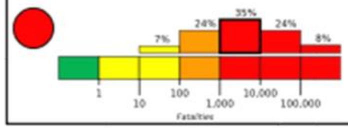
PAGER Version 5

Created: 2 days, 17 hours after earthquake

Estimated Fatalities



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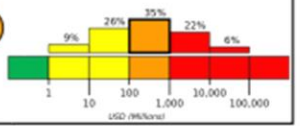

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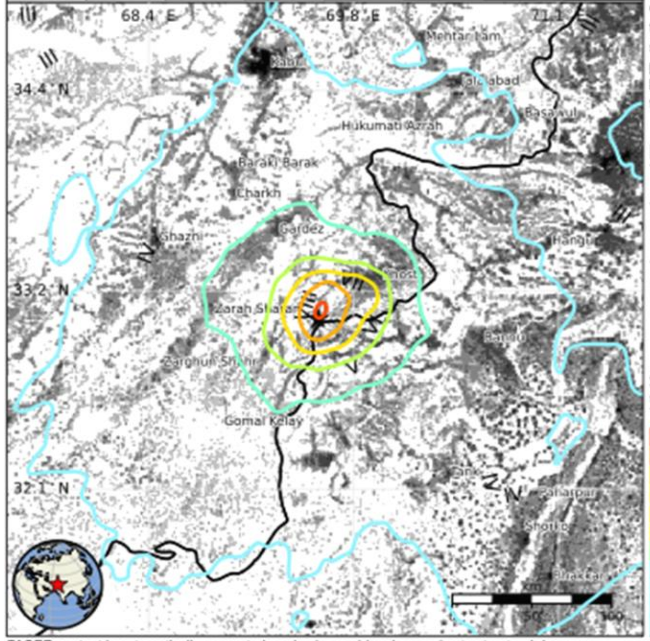

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https://earthquake.usgs.gov/earthquakes/eventpage/us7000hj3u#pager

Event ID: us7000hj3u

Quantifying & Reducing Uncertainties

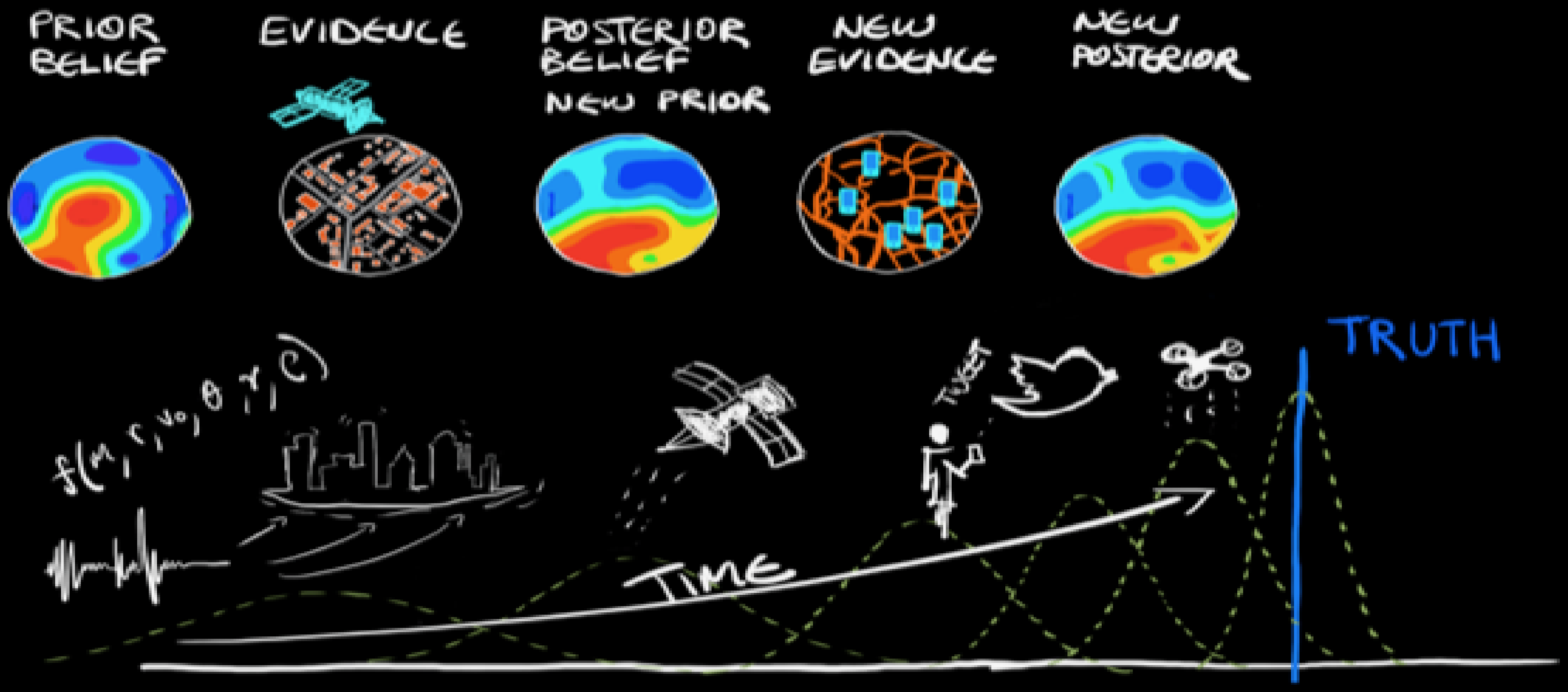
1. Improve prior models:

   - Improved regional (ergodic?) GMM's, IPEs, GMICE.
   - ShakeMap Atlas V4: 250 more loss events since 2010, w/ better data constraints, population, demographics, etc., than previous generation.
   - Loss models – better data, exposure & vulnerability databases, etc.
   - Calibration w/ better uncertainty propagation (ShakeMap, population, losses).

2. Update prior models on-the-fly by adding ground truth observations:

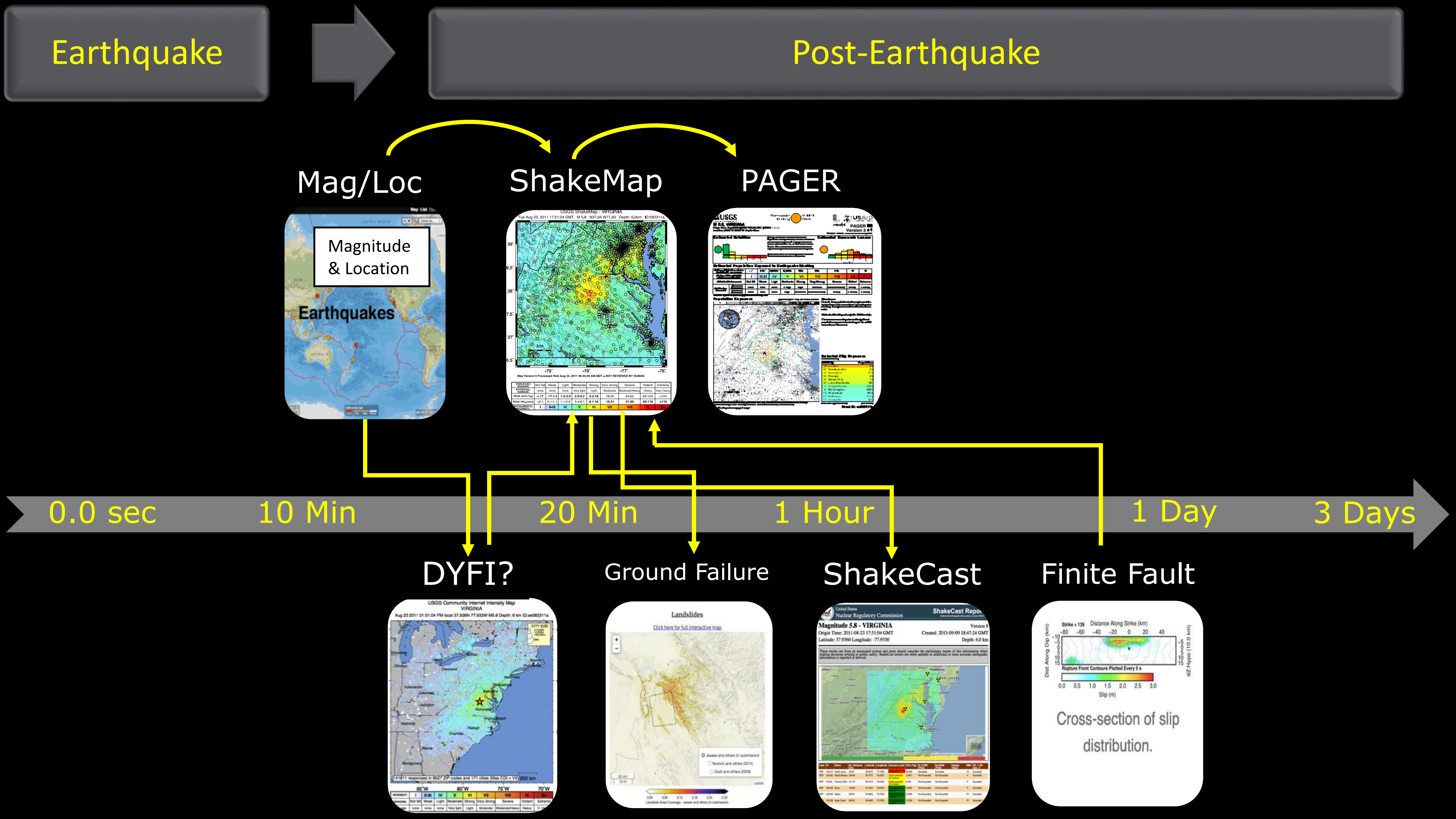
   - Citizen-science, crowd-sourced observations, official/media reports
   - Imagery (InSAR, optical, UAV, lidar)
   - Building & infrastructure damage (site specific) observations
   - Ground failure (specific occurrences of liquefaction & landsliding)

Increasingly more accurate and less uncertain prediction over time through iterative updating and integration of multiple big data sources.



Courtesy of D. Lallemant

USGS Earthquake Information System

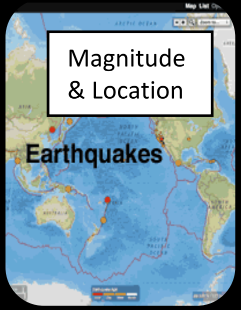


USGS Earthquake Information System

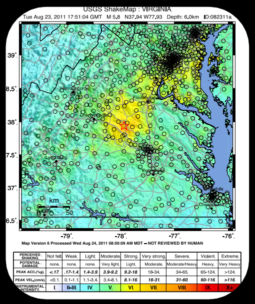
Earthquake

Post-Earthquake

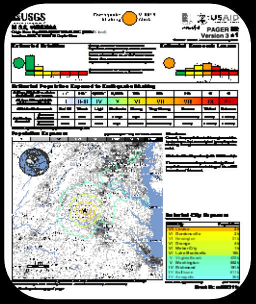
Mag/Loc



ShakeMap



PAGER

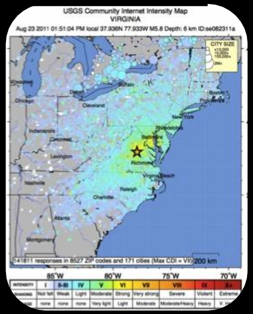


Reporting

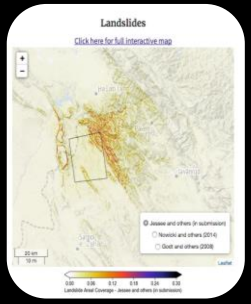
Imagery

0.0 sec — 10 Min — 20 Min — 1 Hour — 1 Day — 3 Days

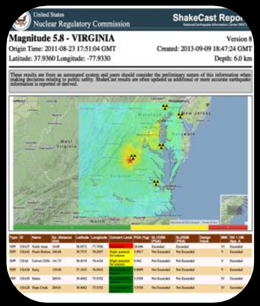
DYFI?



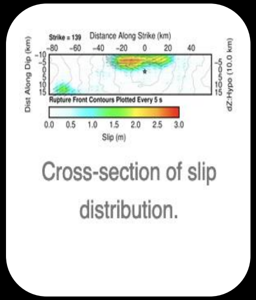
Ground Failure



ShakeCast

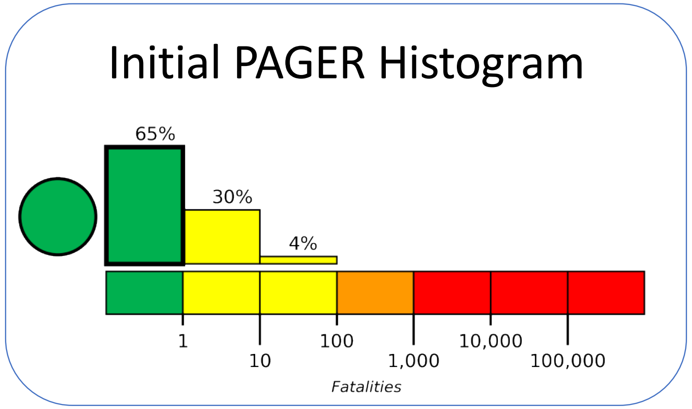


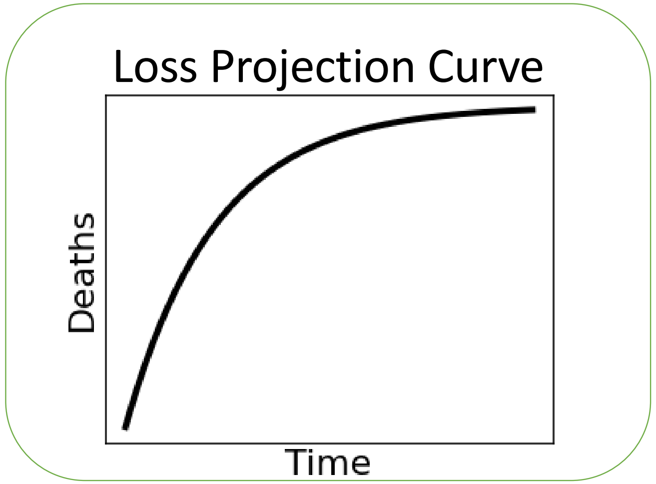
Finite Fault



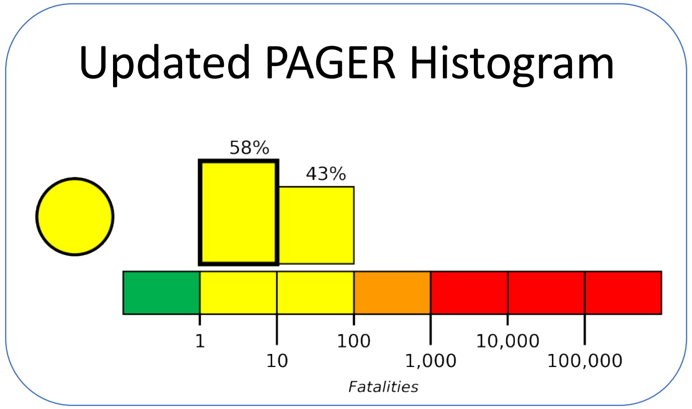
Introduction to the updating framework

- Goal: Improve PAGER's fatality estimates in the hours/days after an earthquake





Bayesian Update



Reported Fatalities

Time	Deaths
2 hours	2
6 hours	8

Slide courtesy of Davis Engler, CSM/USGS

Research Paper

EERI EARTHQUAKE SPECTRA

An efficient Bayesian framework for updating PAGER loss estimates

Earthquake Spectra
1–24

DOI: 10.1177/8755293020944177
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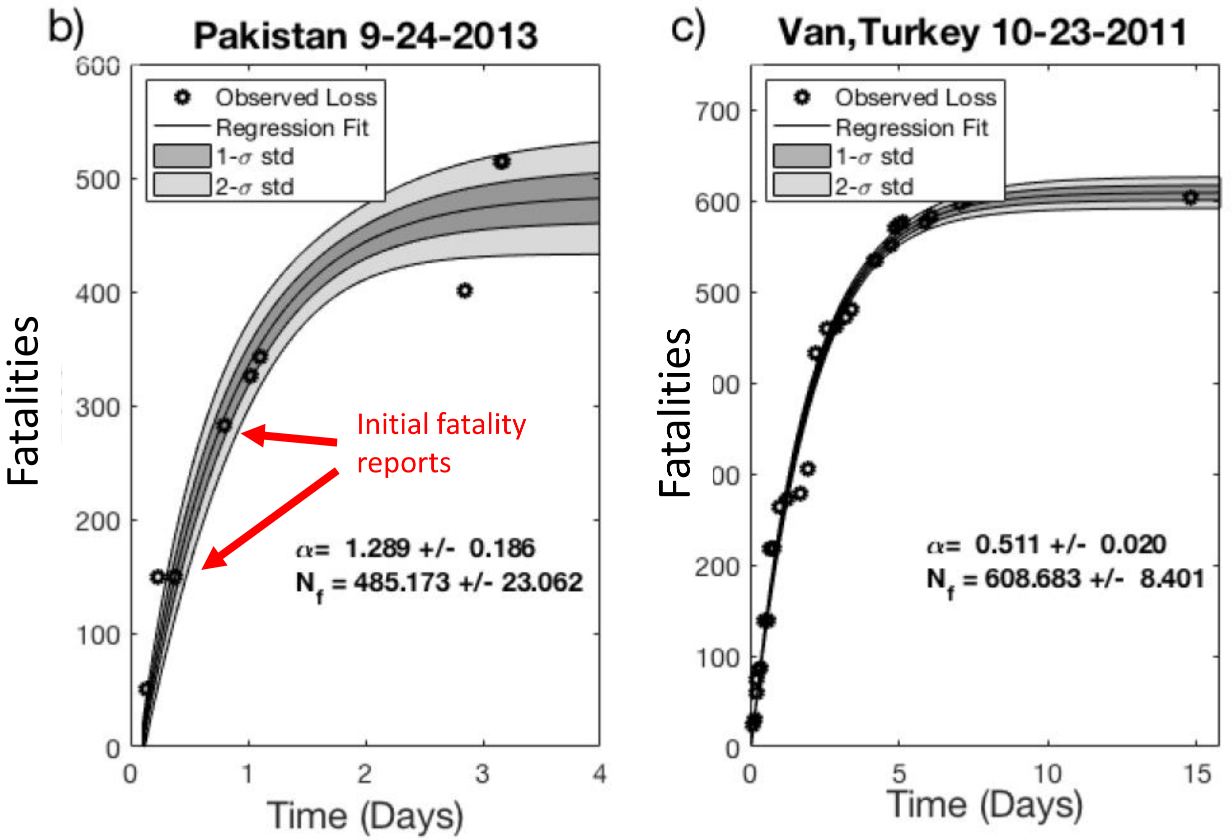
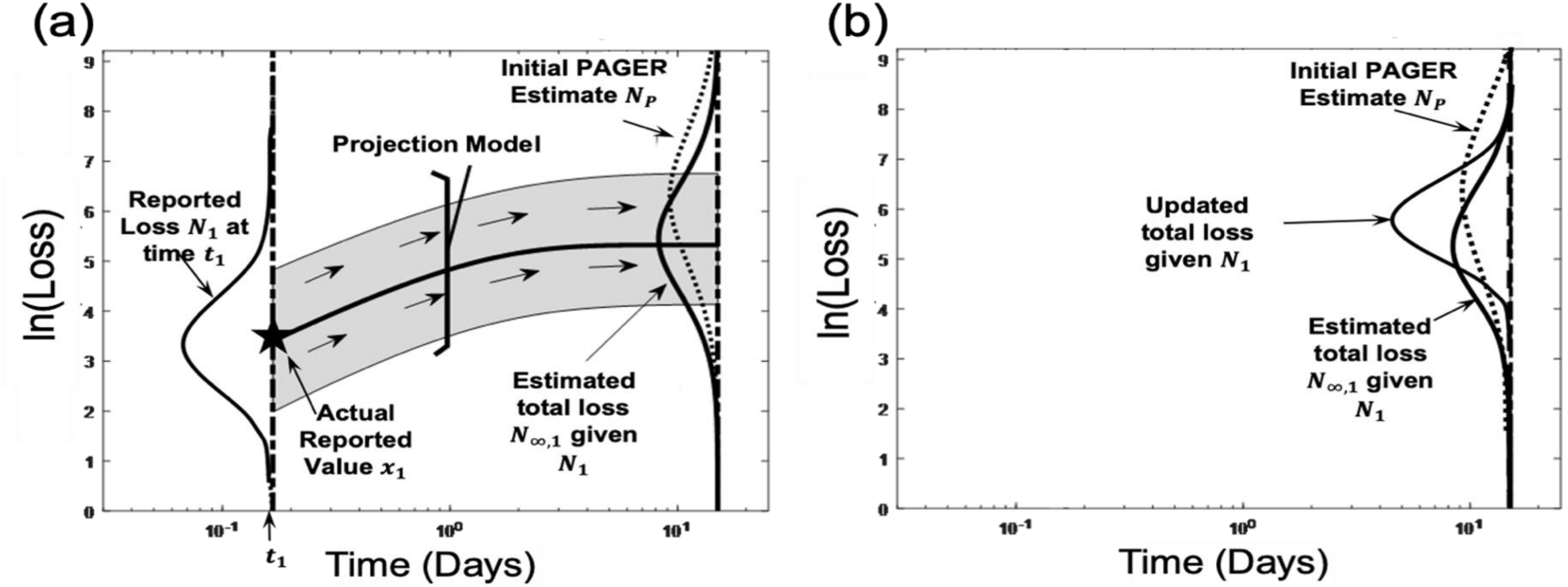
Hae Young Noh, M.EERI[1], Kishor S Jaiswal, M.EERI[2], Davis Engler[2,3], and David J Wald, M.EERI[4]

Abstract
We introduce a Bayesian framework for incorporating time-varying noisy reported data on damage and loss information to update near real-time loss estimates/alerts for the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER) system. Initial loss estimation by PAGER immediately following an earthquake includes several uncertainties. Historically, the PAGER's alerting on fatality and economic losses has not incorporated location-specific reported data on physical damage or casualties for a given earthquake. The proposed framework provides the ability to include early reports on fatalities at any given time and improve the overall impact forecast for the earthquake. The reported data on fatalities or damage are generally incomplete and noisy, especially in the early hours of the disaster. To address these challenges, we develop a recursive Bayesian updating framework that takes into account the loss projection model and the measurement and model uncertainties. The framework is applied to loss data for three example earthquakes, and the results show that the proposed updating improves the loss estimates and alert level to the correct level within the first day of the earthquake.

Keywords
PAGER, Bayesian updating, casualty, loss modeling, forecast

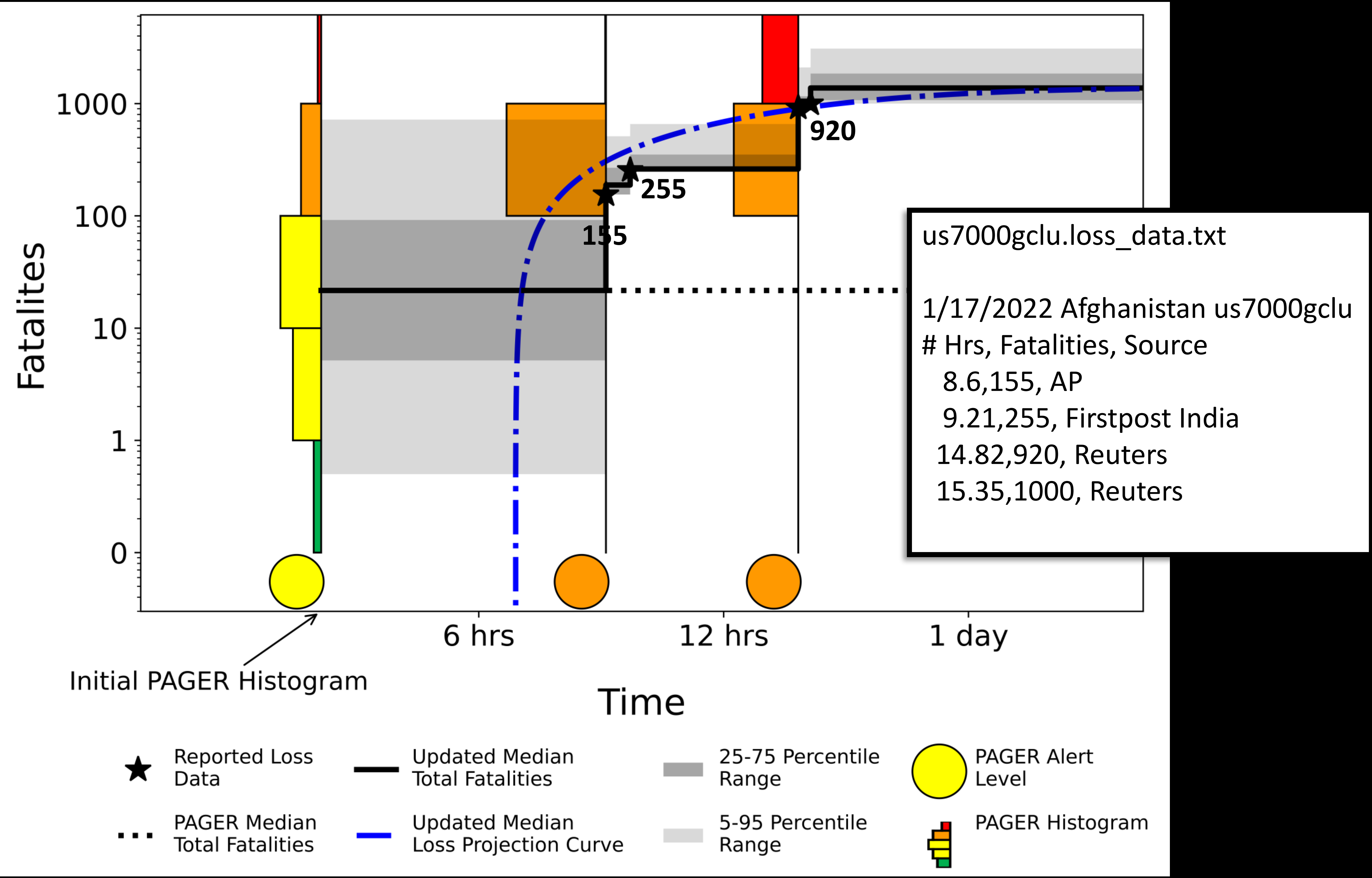
Date received: 2 June 2020; accepted: 8 June 2020





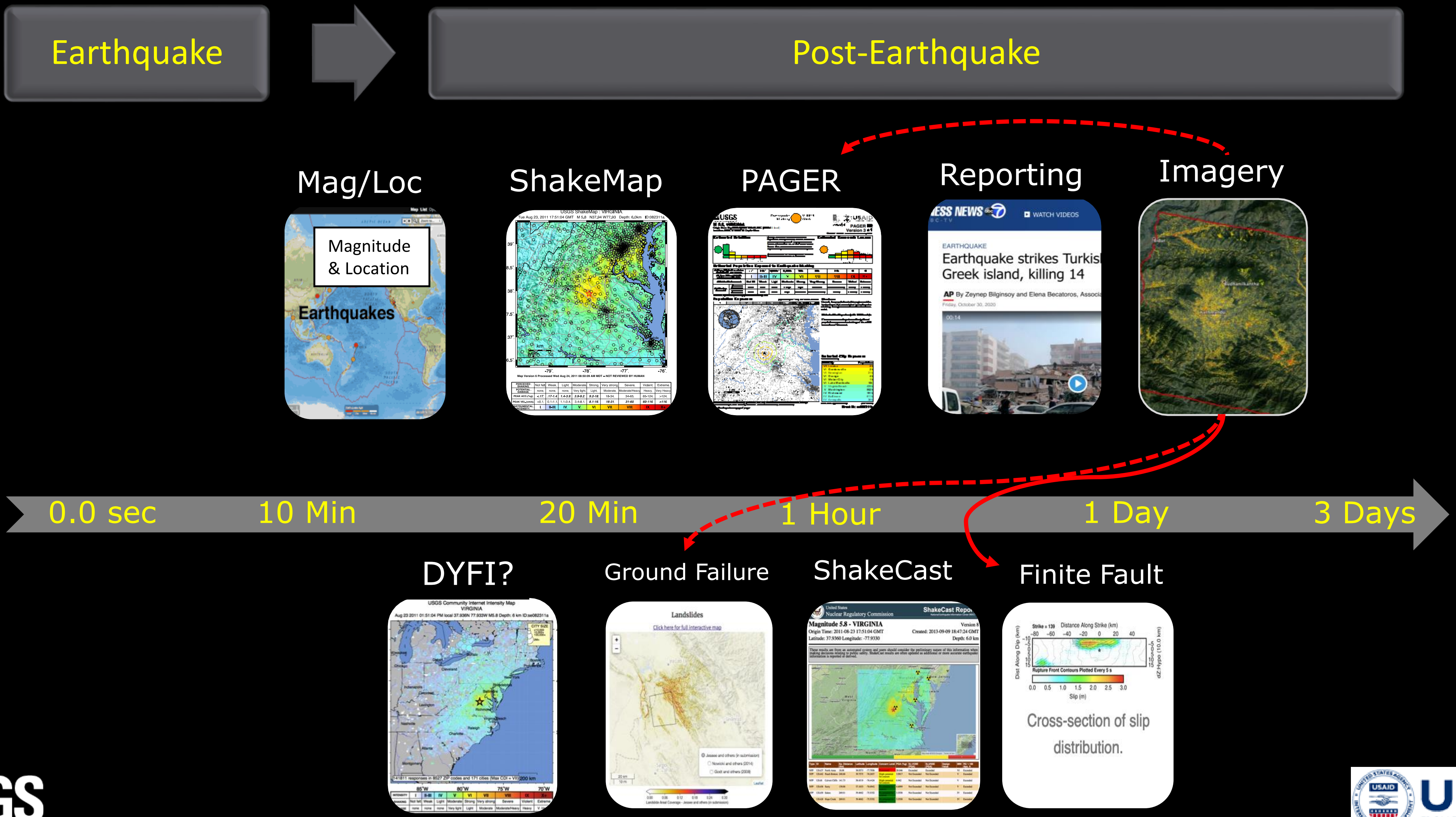
(a) The projection step, where the reported loss data at time t_1 is used to obtain an estimate of total loss based on the loss projection model. (b) The updating step, using the estimated total loss given the report at time t_1 as an observation of total loss, the PAGER loss distribution is updated to obtain a new estimate of the total loss distribution.

Noh, Engler, Jaiswal, & Wald (2020)



Fatalites
1000
100
10
1
0
6 hrs
12 hrs
1 day
Time
155
255
920
Initial PAGER Histogram
us7000gclu.loss_data.txt
1/17/2022 Afghanistan us7000gclu
Hrs, Fatalities, Source
8.6,155, AP
9.21,255, Firstpost India
14.82,920, Reuters
15.35,1000, Reuters
Reported Loss Data
Updated Median Total Fatalities
25-75 Percentile Range
PAGER Alert Level
PAGER Median Total Fatalities
Updated Median Loss Projection Curve
5-95 Percentile Range
PAGER Histogram

USGS Earthquake Information System



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NASA/JPL Damage Proxy Map (DPM) & other examples

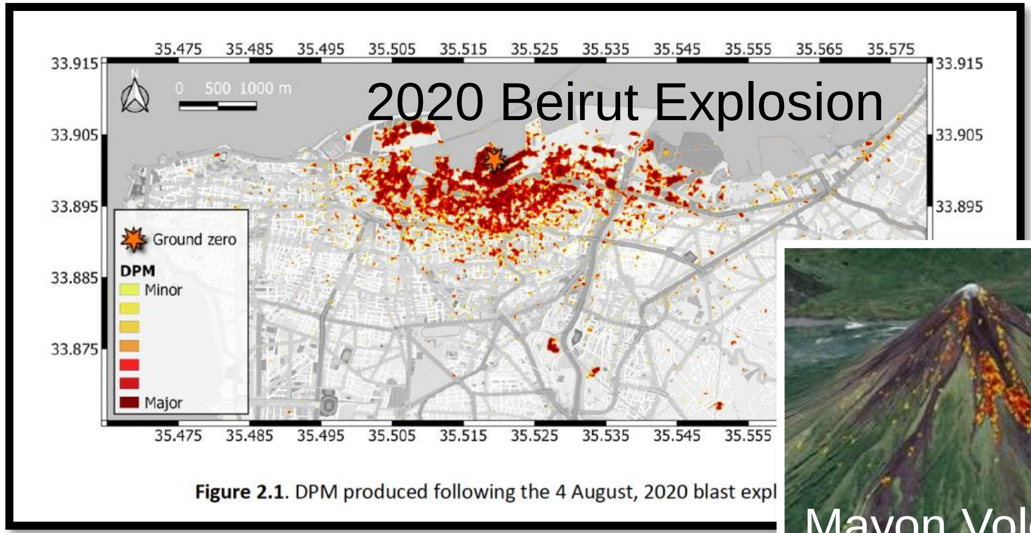


Figure 2.1. DPM produced following the 4 August, 2020 blast expl

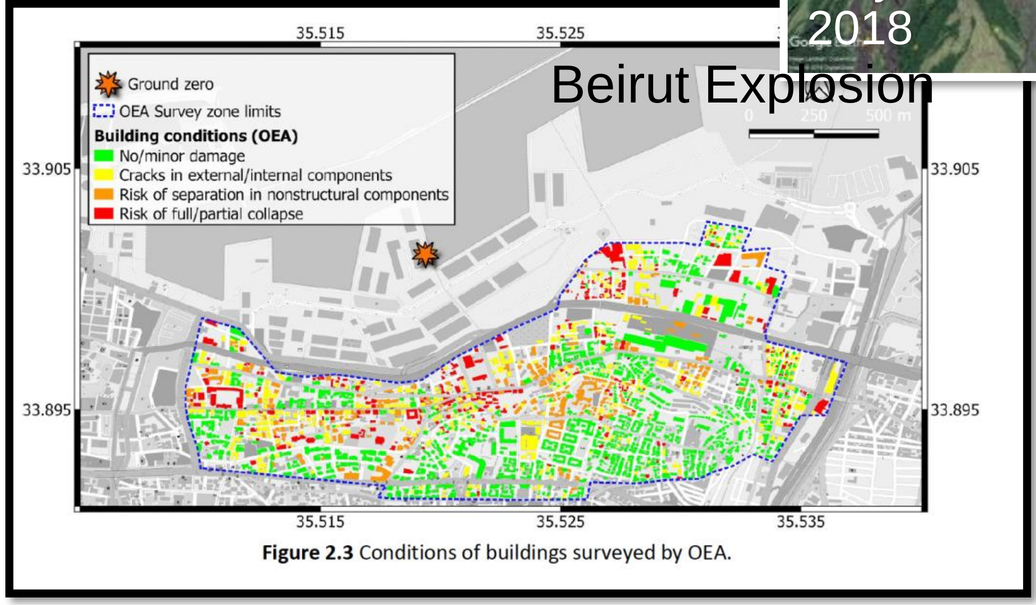
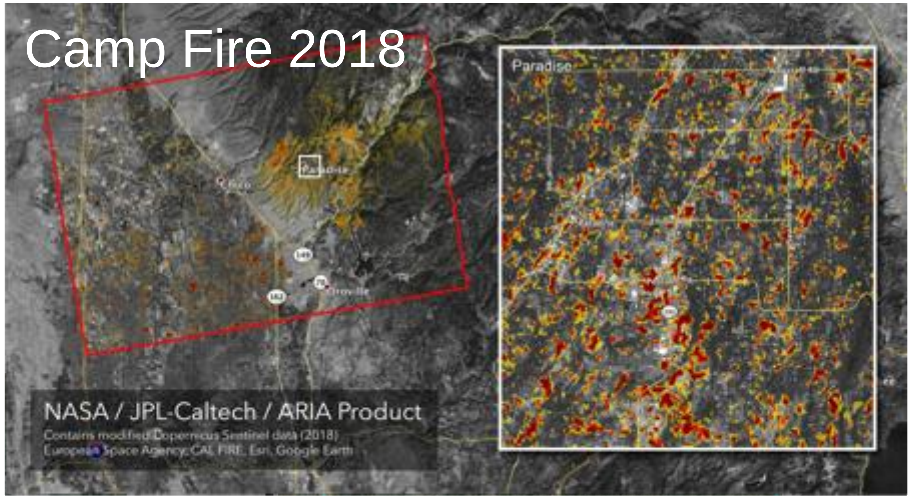
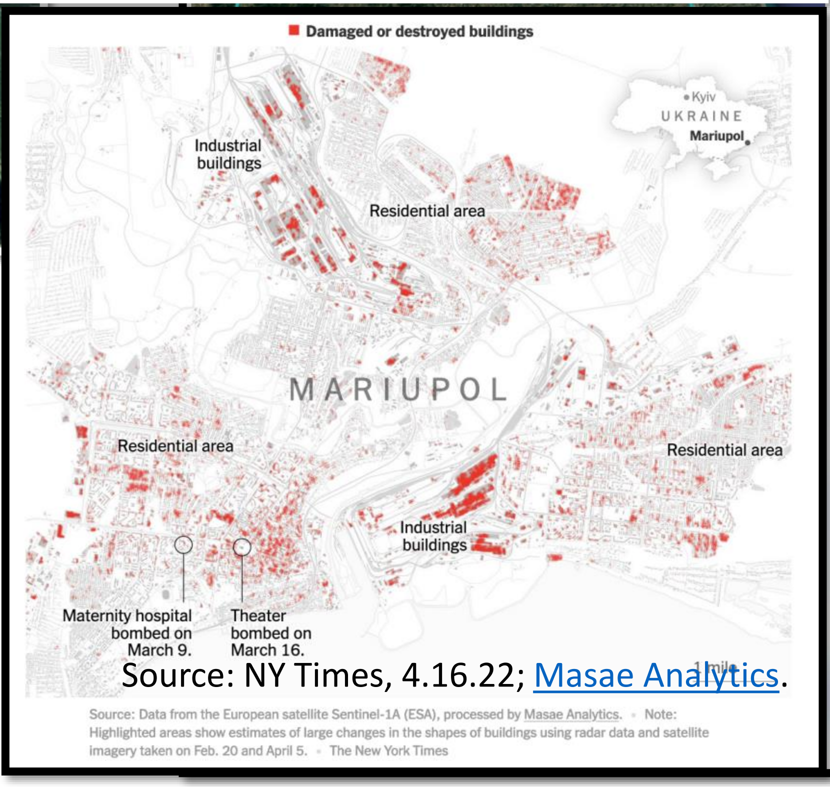


Figure 2.3 Conditions of buildings surveyed by OEA.

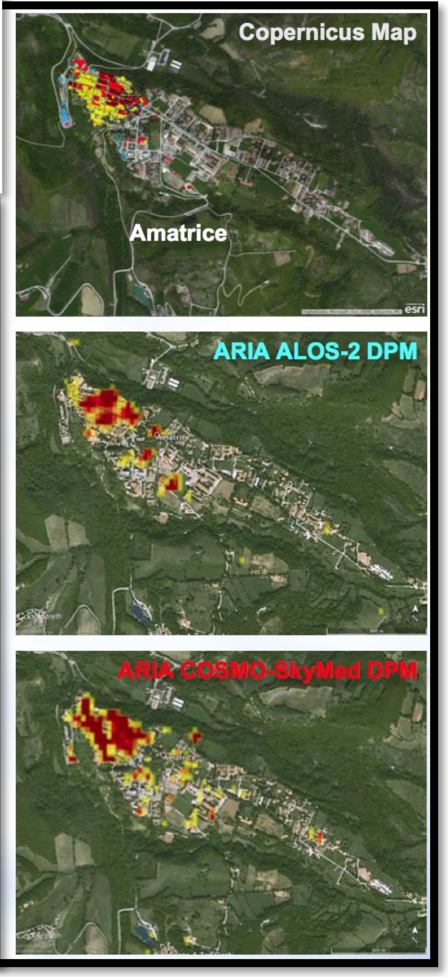




Source: NY Times, 4.16.22; [Masae Analytics](#).

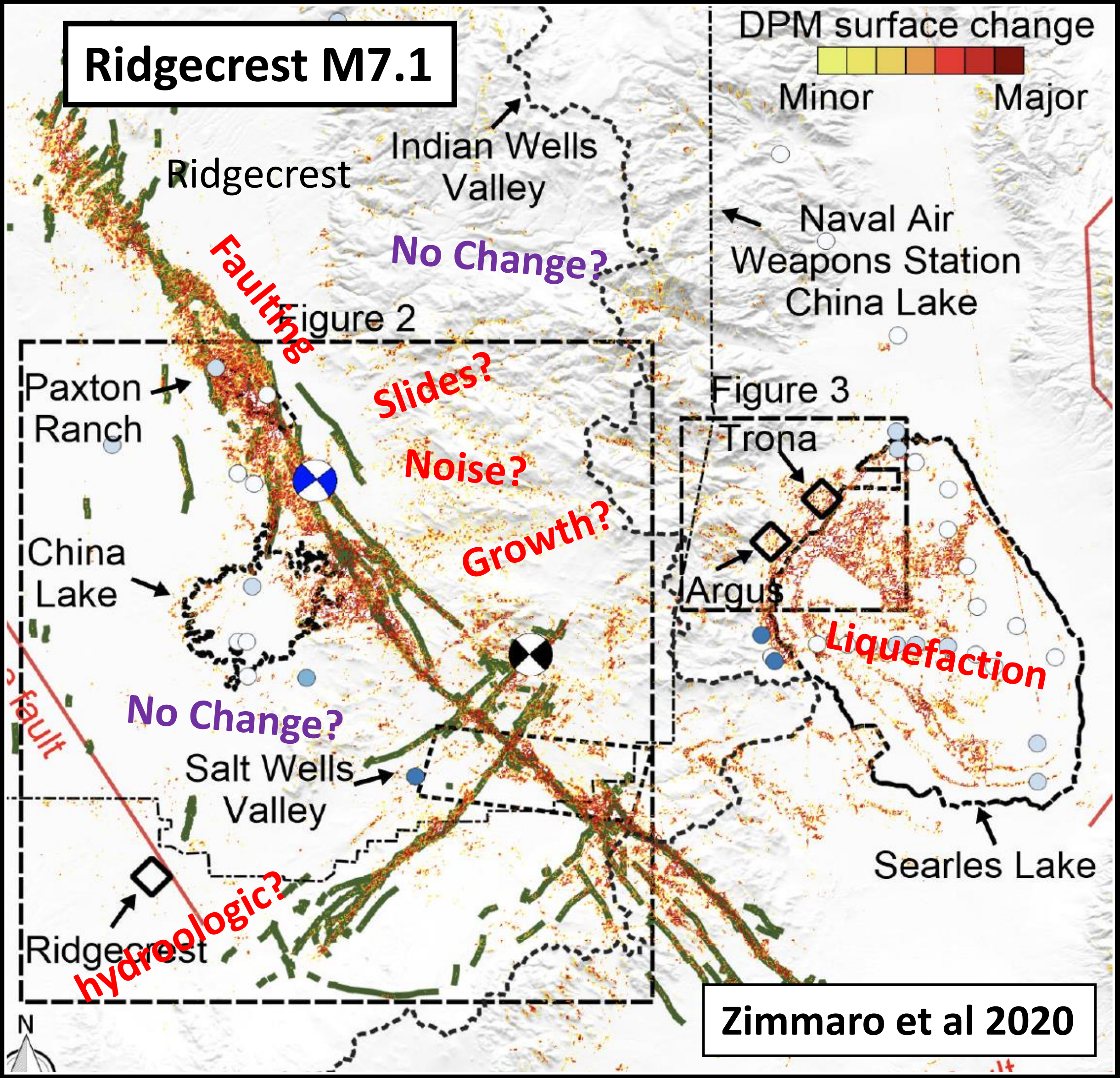
Source: Data from the European satellite Sentinel-1A (ESA), processed by Masae Analytics. · Note: Highlighted areas show estimates of large changes in the shapes of buildings using radar data and satellite imagery taken on Feb. 20 and April 5. · The New York Times

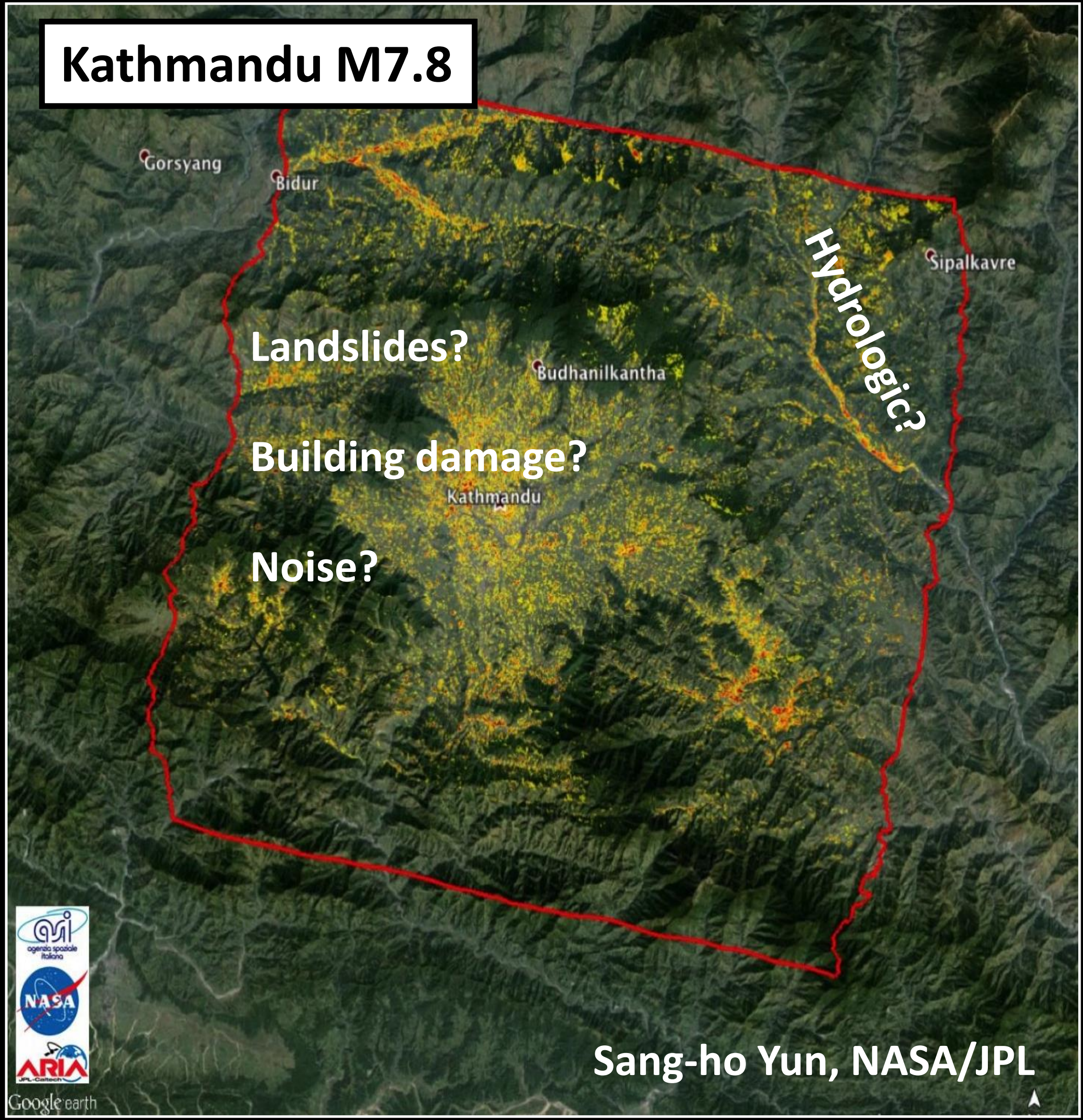
2016 Amatrice Earthquake



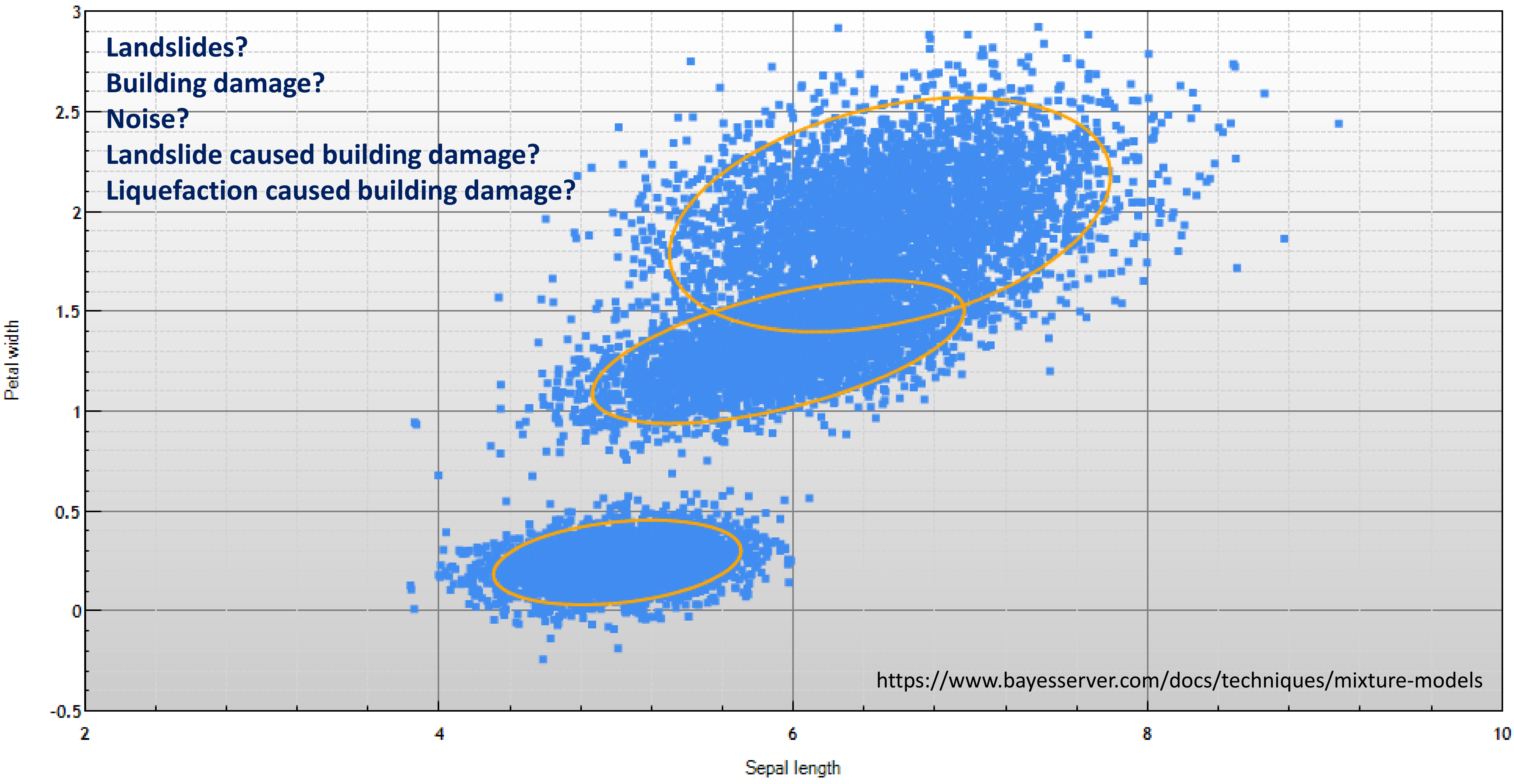
Images from S. Yun, EOS/NTU; Masae Analytics

InSAR “Damage Proxy Maps” (DPMs):Pre-post event changes in image correlation



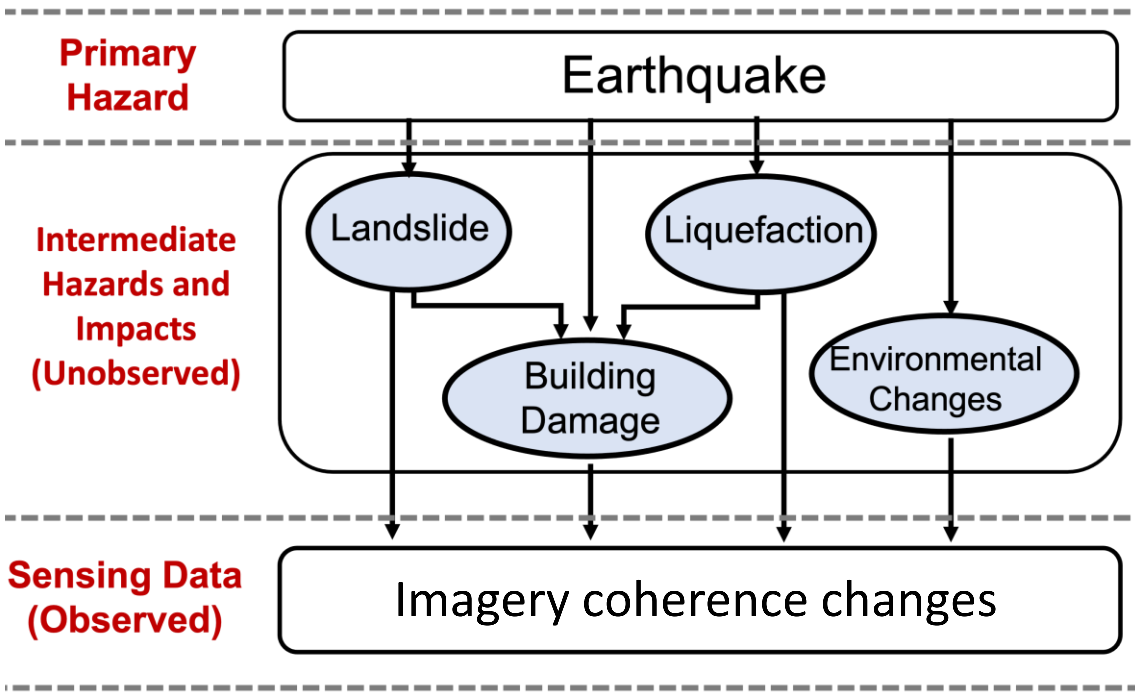


A mixture model - a collection of multivariate gaussian distributions

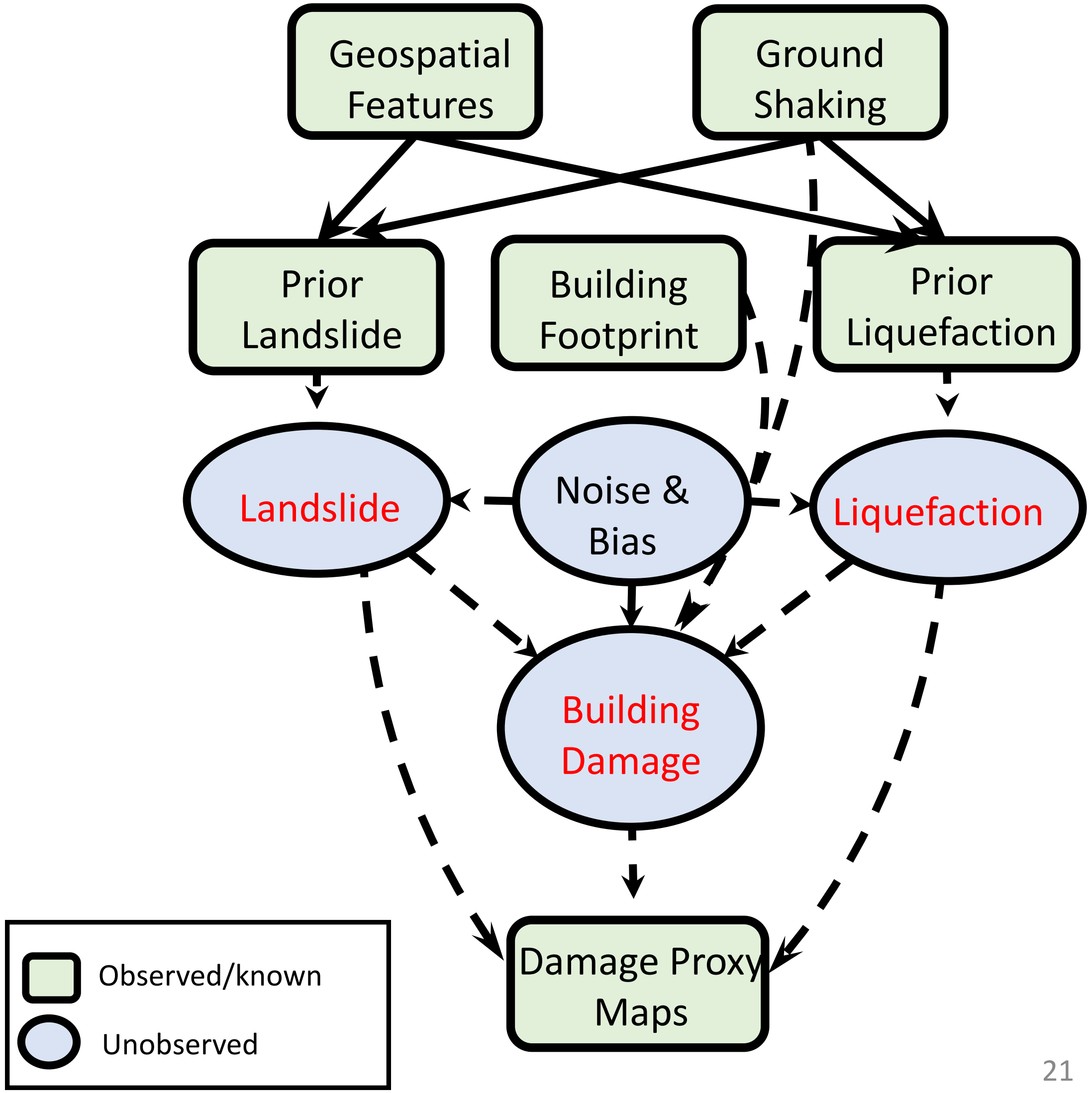


Causal graph *model to solve for complex interactions*

Conceptual Model

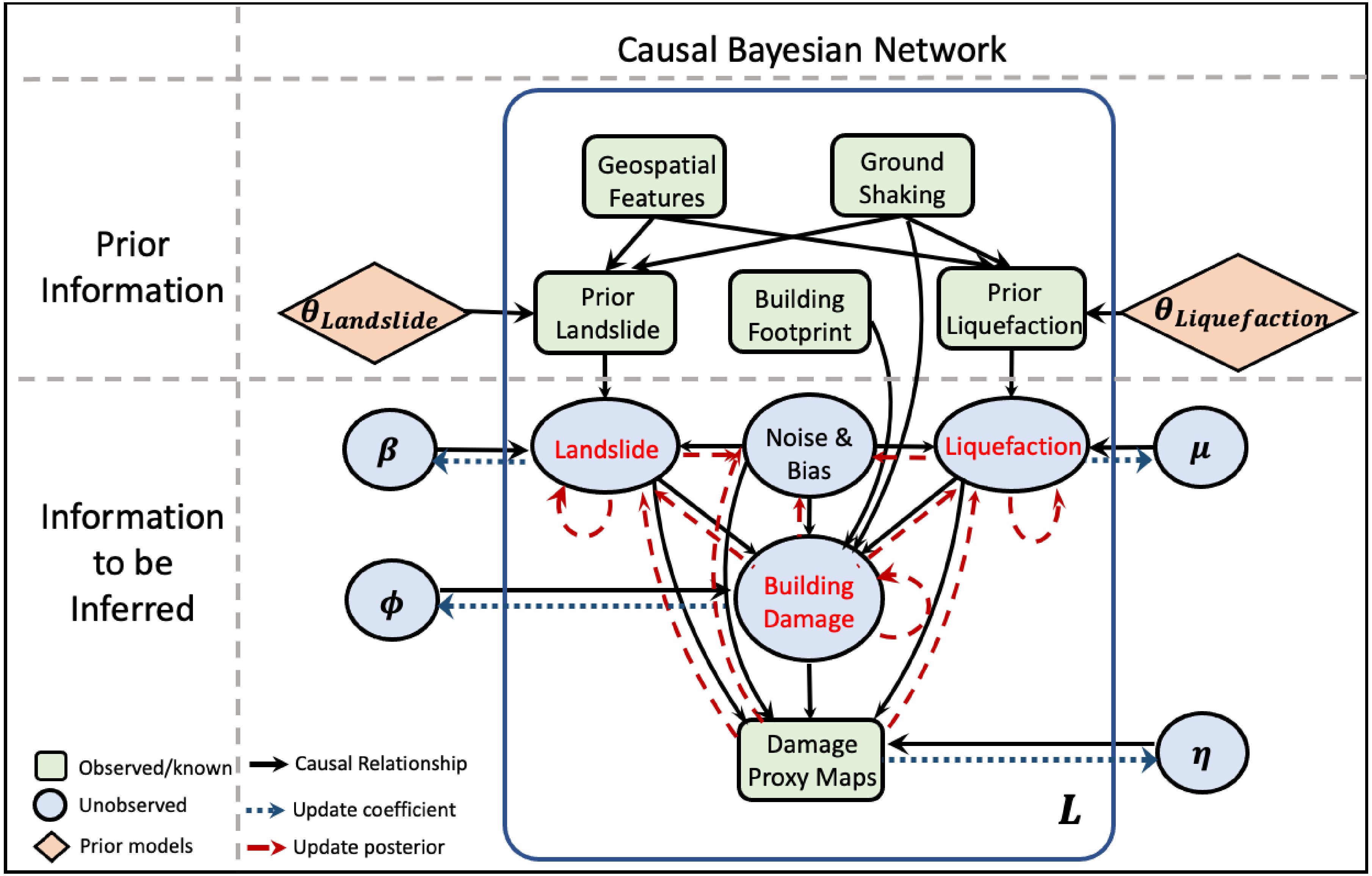


Mathematical Model



See Susu Xu et al. this meeting (Thurs)

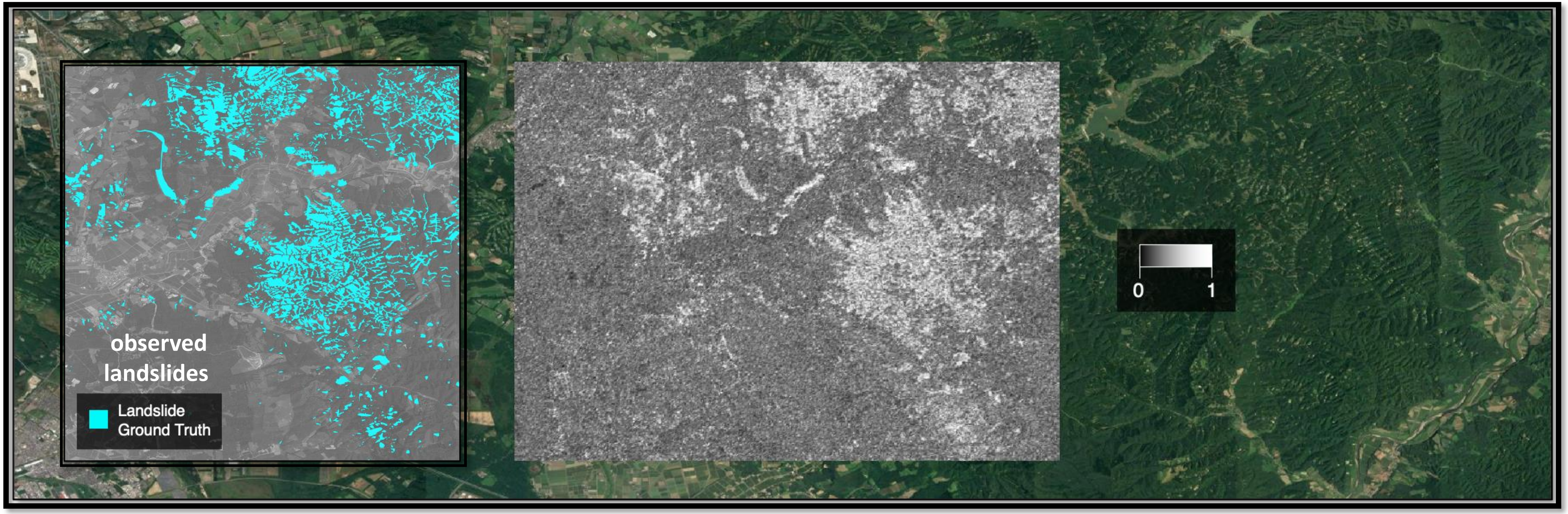
Causal graph model to approximate complex interactions



Xu, Dimaska, Wald, & Noh (2021)

Example Results – An <u>easy</u> case

The 2018 Hokkaido, Japan Earthquake of September 2018 (M6.6)



<u>DPM3</u>: 30m resolution, covered the towns of Atsuma and Abira, generated by ARIA team using the SAR images from the ALOS-2 satellites of the Japan Aerospace Exploration Agency

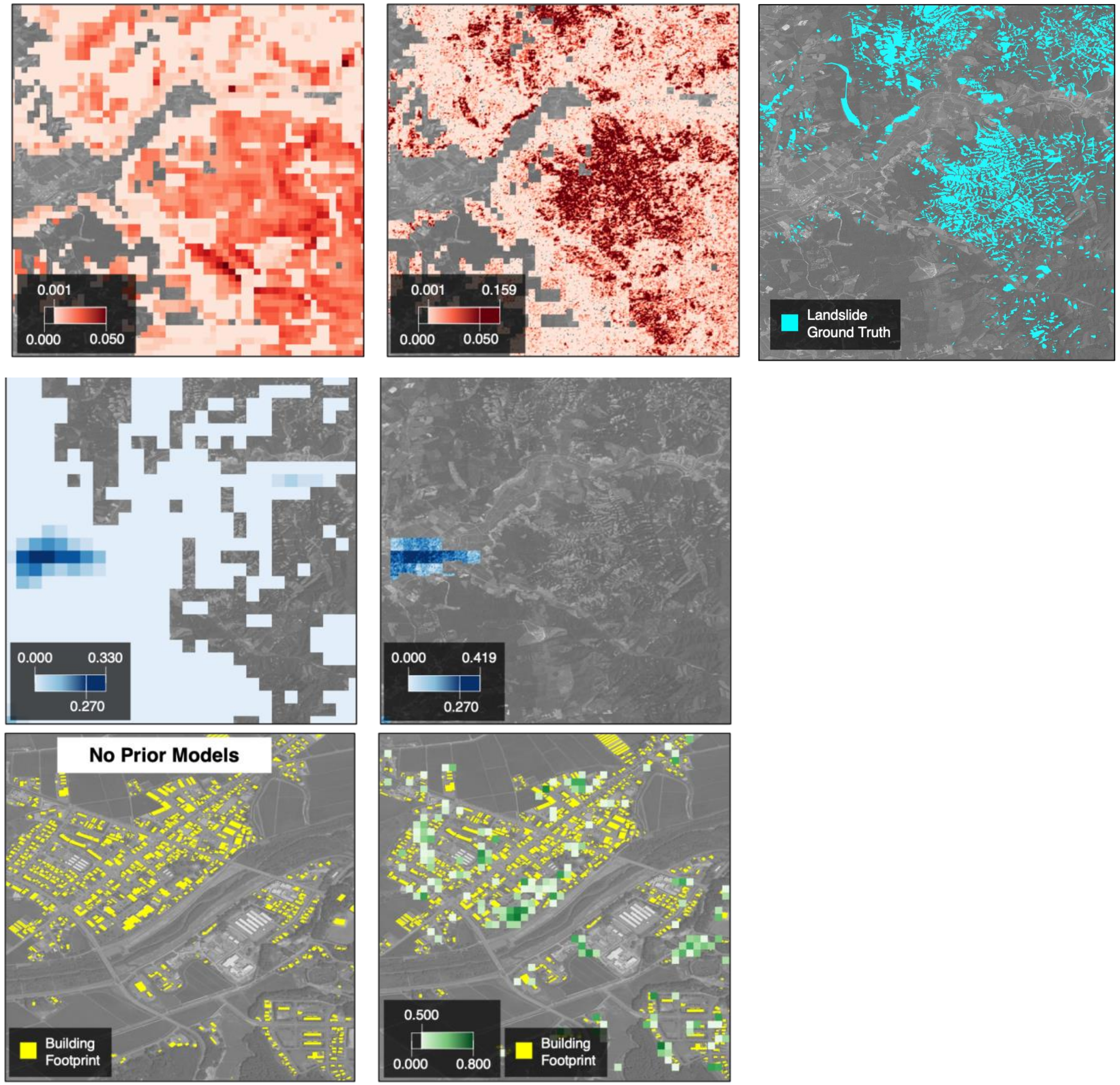
Susu Xu, Dimaska, Wald, & Noh (2021)

Atlas V4 prior | Posterior w/ V4 prior | **observed slides**

Landslide

Liquefaction

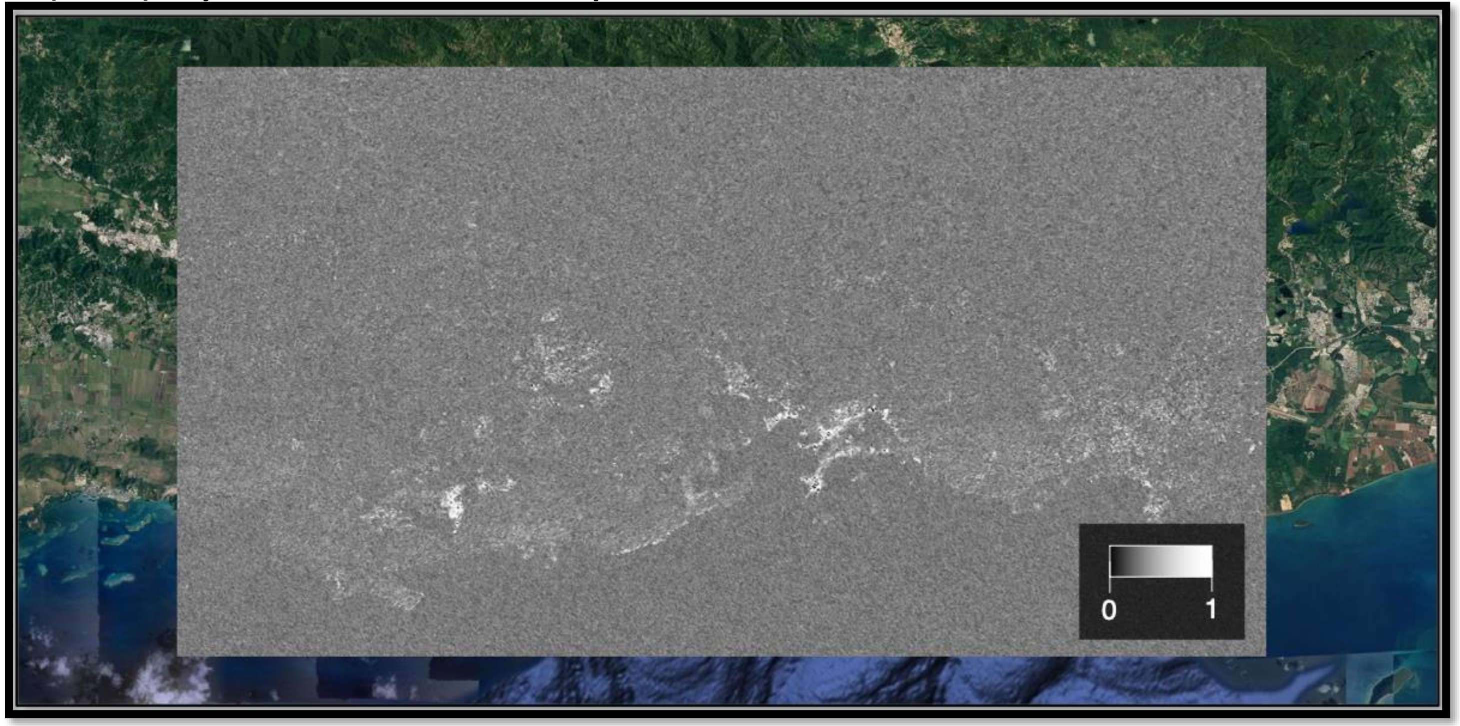
Building Damage



Susu Xu, Dimaska, Wald, & Noh (2021)

Example Results – A more difficult case

The 2020 Puerto Rico earthquake struck the southwest area of Puerto Rico on January 7, 2020, at 4:24 am (AST) by a Mw 6.4 earthquake



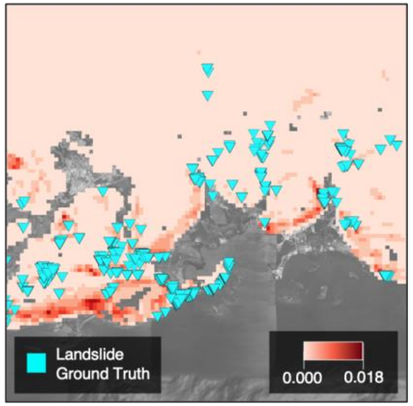
DPM2: 30m resolution, covered the towns of Atsuma and Abira, generated by ARIA team using the SAR images from the Copernicus Sentinel-1 satellites of the European Space Agency

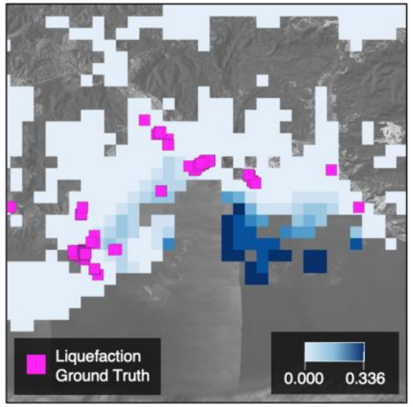
Susu Xu, Dimaska, Wald, & Noh (2021)

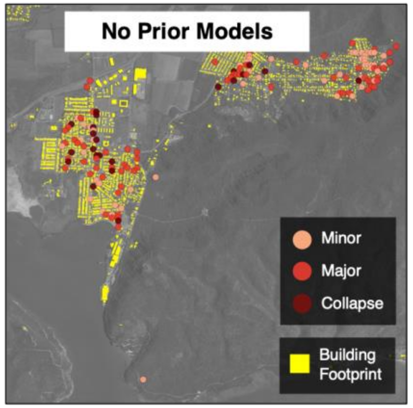
Results

Prior | Liquefaction | Building Damage

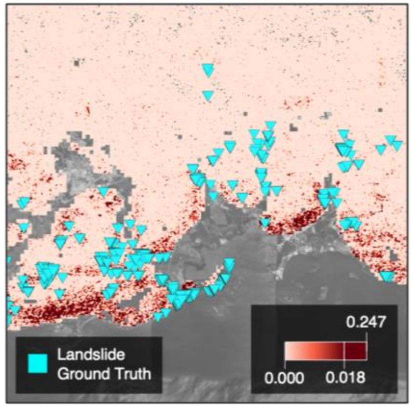
Landslide

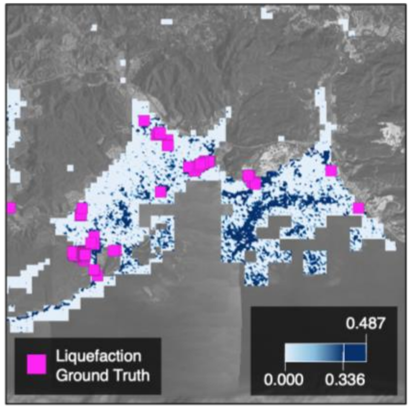


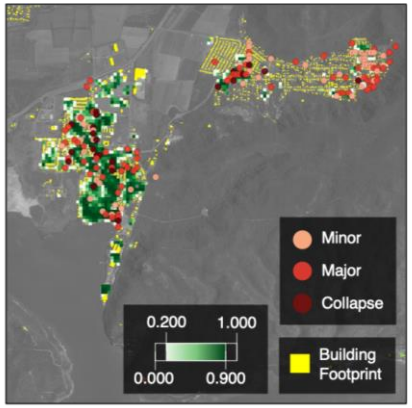




Our model







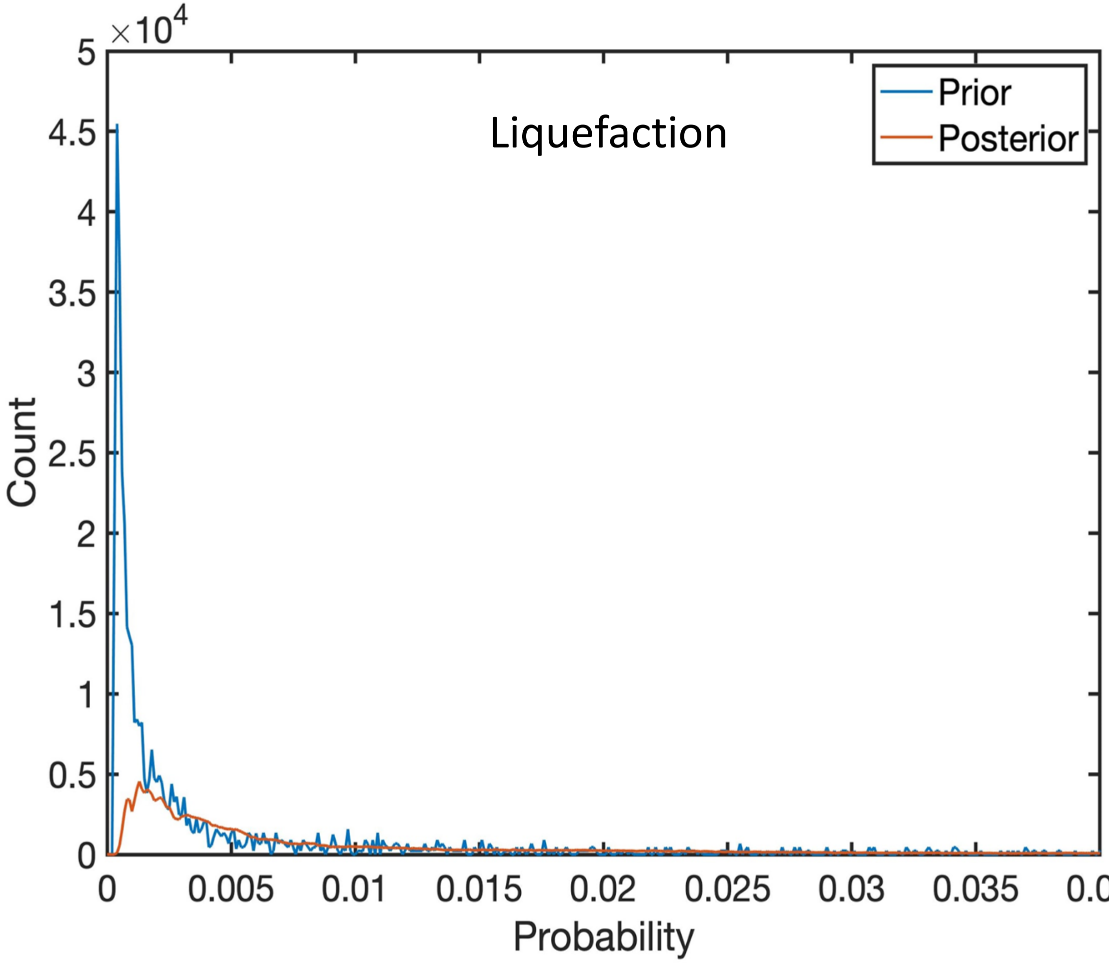
Cross-entropy loss:
Prior: 0.0238
Posterior: 0.0175
AUC:
Prior: 90.36 %
Posterior: 90.83%

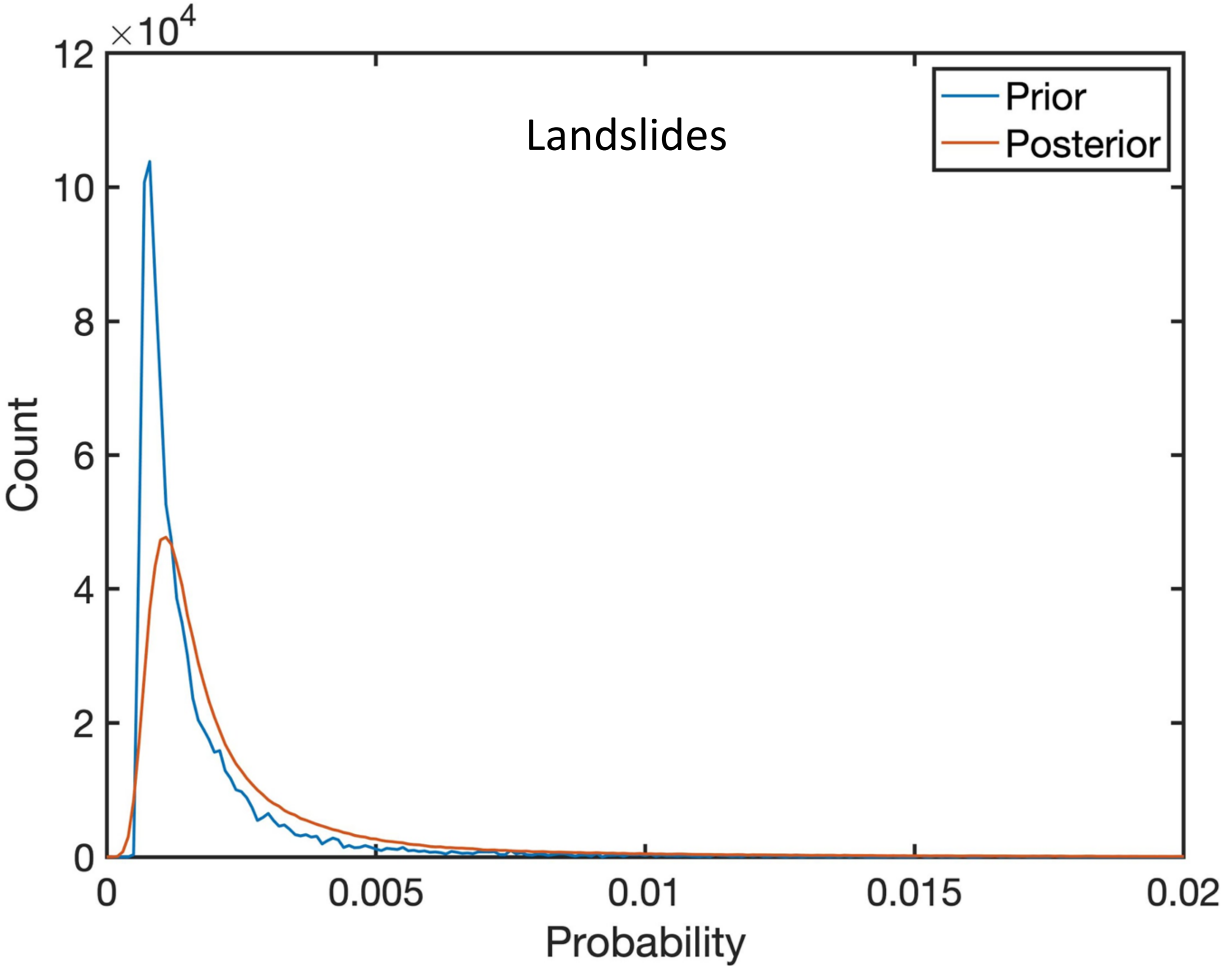
Cross-entropy loss:
Prior: 0.0301
Posterior: 0.0095
AUC:
Prior: 82.87 %
Posterior: 90.49%

Binary-class AUC:
Prior: 69.50 %
Posterior: 92.36%

Distribution of Posterior & Prior over the map

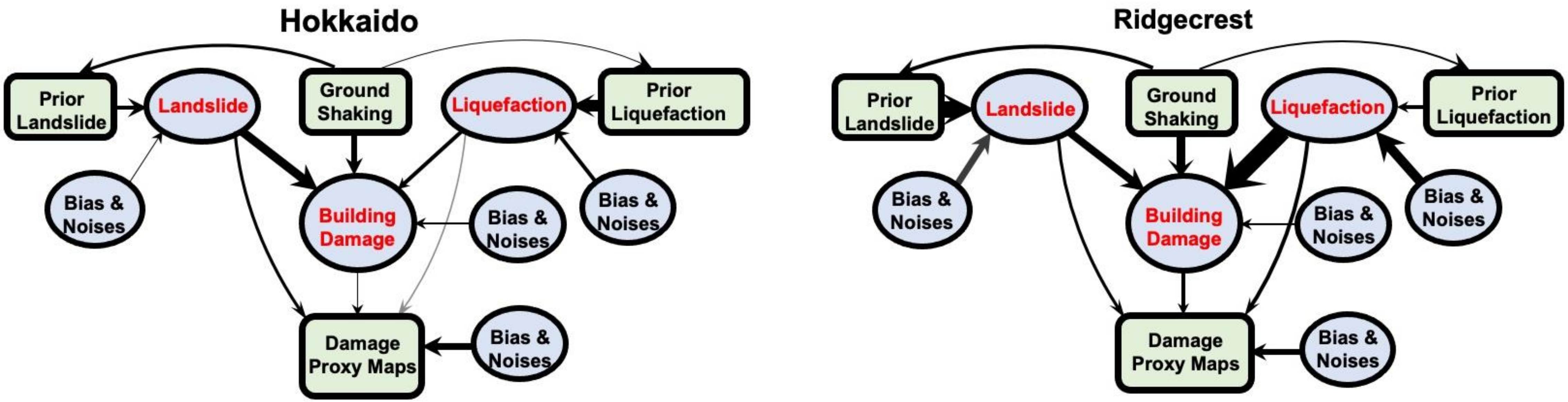
(posterior has fewer low-probability areas)





Results

Causality quantification for different events to reveal the causation mechanisms



Ongoing efforts …

- Improvements to *a priori* ground failure models (work in progress)
- Implement *a priori* building damage models (PAGER semi-empirical models)
- Testing approach on more earthquake datasets (<u>but need</u>: good DPM, good ShakeMap, building damage data, and digital GF datasets
- Update the causal graphical model with incoming ground truth observations

Quantifying & Reducing Uncertainties

1. Improve prior models

2. Update prior models on-the-fly by adding ground truth observations

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Civil Engineer

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Geological Survey

The **USGS ShakeCast Team** is seeking app's for a Civil Engineer/ Programmer at the National Earthquake Information Center, in **Golden, Colorado**

Summary | This job is open to | Duties | Requirements | How you will be evaluated | Required documents | How to Apply

Summary

What General Information Do I Need To Know About This Position?

The **government-wide** direct hire authority for **Civil Engineer/0810** is being used to fill this position.

GS-11 Salary: $72,995 (Step 01) to $94,889 (Step 10);
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NOTE: First time hires to the Federal Government are typically hired at the Step 01.

Learn more about this agency

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Overview

Help

Job closed

Open & closing dates
06/27/2022 to 07/25/2022

Salary
$72,995 - $113,743 per year

Pay scale & grade
GS 11 - 12

Location
Golden, CO
Few vacancies

Apply at USAJobs (https://www.usajobs.gov/job/659923500)
or for more information contact David Wald (wald@usgs.gov)