Developing & Implementing an International Macroseismic Scale (IMS)
for
Earthquake Engineering, Earthquake Science & Rapid Damage Assessment

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T. Goded, R. Spence, A. Hortacsu, S. Loos, & the USGS Powell Center IMS Workshop Participants

GEM Conference
June 13th - 14th, 2023
Bergamo, Italy

USGS *National Earthquake Information Center (NEIC)*

Macroseismology is dead.

Long live Macroseismology!

Outline/Summary

- Uses & importance of macroseismic intensity data
    - Historical earthquake quantification
    - Engineering fragilities, loss modeling & risk analyses
    - Communicating earthquake shaking & impacts
    - [Sociological analyses of human behavior in earthquakes]

- Challenges with modern macroseismic practices
    - Limitations of ”Did You Feel It?” (lower-to-moderate intensities levels only)
    - Limitations of Modified Mercalli Intensity (MMI, the standard in the U.S. & N.Z.)
    - Incompatibilities among macroseismic scales & data worldwide

- Moving forward: Developing/Implementing an International Macroseismic Scale (IMS)
    - Implementing EMS-98 in the US & New Zealand. EMS-98 is an ***engineering*** scale
    - We’d like to modernize macro assignments by employing recon & inspection teams
    - GEM’s role in an IMS

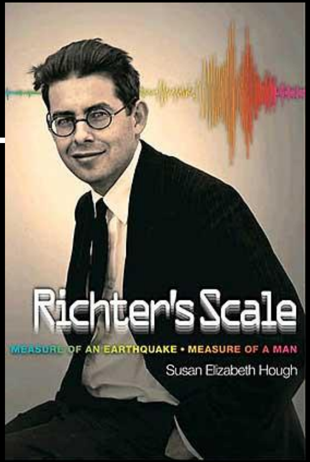
USGS

A (USGS-centric) History of Macroseismic Intensity Scales

- Earliest use of macroseismic observations was about late 1700’s
- First intensity scale was the Rossi-Forel Scale of 1883 (10-degree)
- Sieberg (1912) became the foundation modern 12-degree scales; Mercalli-Cancani-Sieberg Scale—or MCS Scale—is still in use in Italy.
- The 1923 version was translated into English by Wood & Neumann (1931), becoming the Modified Mercalli Scale (MMI Scale). Richter overhauled MMI in 1956 (but refrained from adding his name in case of confusion with "Richter Scale”).
- USGS’ Jim Dewey made practical modifications to MMI, now employed by USGS.
- USGS’ still uses MMI, as is the basis of the popular DYFI system, started in 1999.
- EMS-98 Published in 1998. Edited by Gottfried Grunthal. Modern, engineering-centric

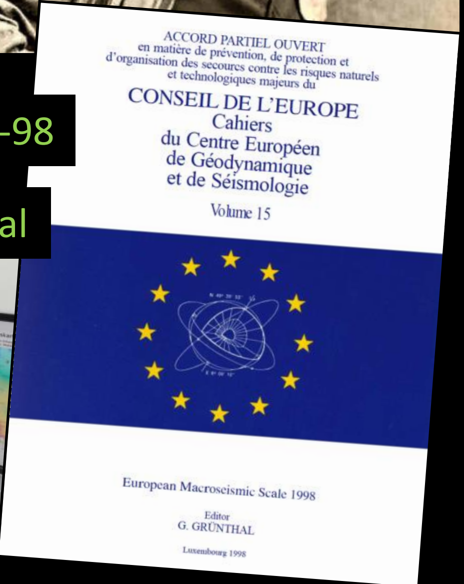
* See Roger Musson’s (2010) discussion on the evolution of scales.

Charlie
Richter



Giuseppe
Mercalli

EMS-98



ACCORD PARTIEL OUVERT
en matière de prévention, de protection et
d’organisation des secours contre les risques naturels
et technologiques majeurs du

CONSEIL DE L’EUROPE
Cahiers
du Centre Européen
de Géodynamique
et de Séismologie

Volume 15

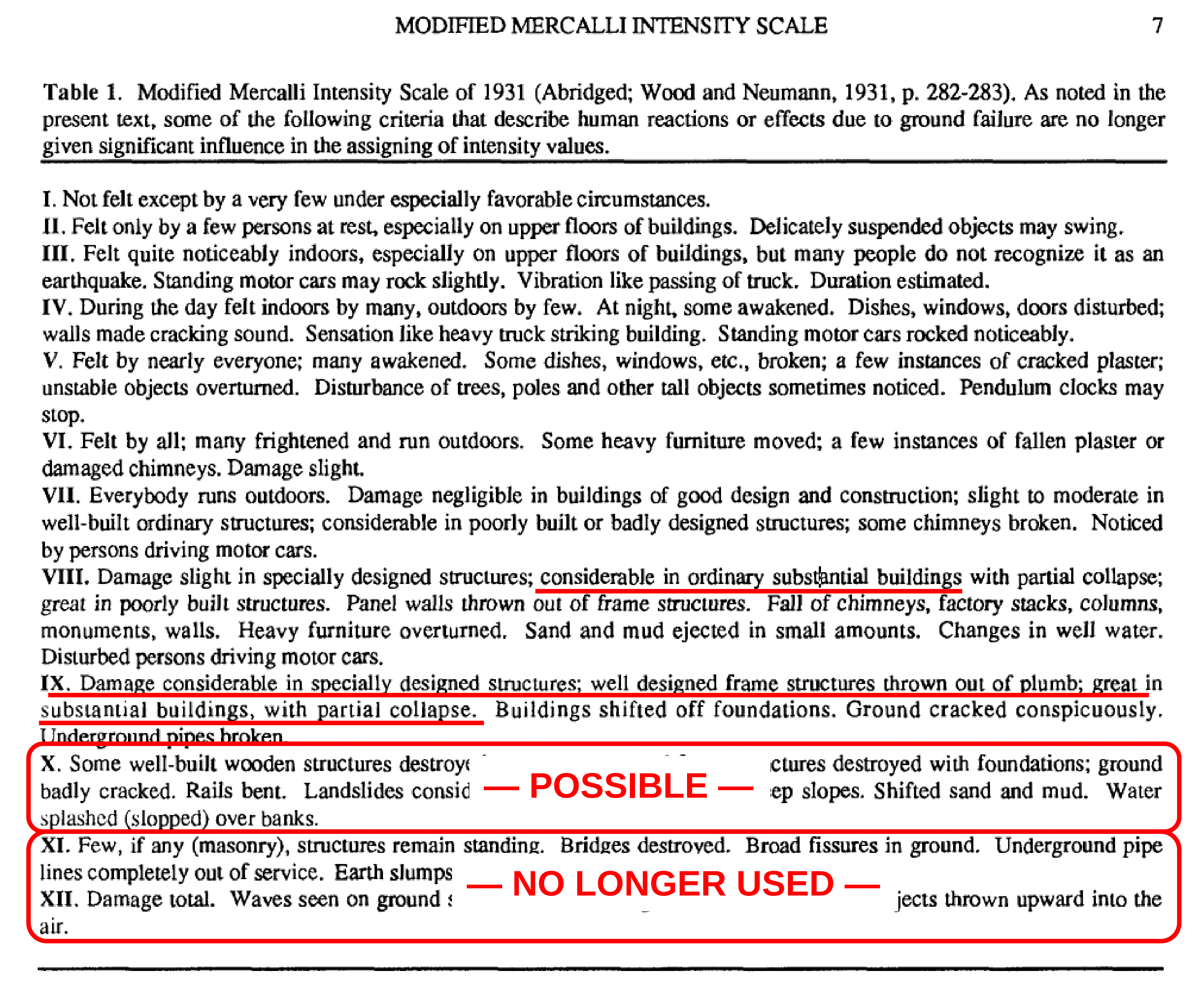
European Macroseismic Scale 1998

Editor
G. GRÜNTHAL

Luxembourg 1998

Gottfried Grunthal

Modified Mercalli Intensity (MMI)



MODIFIED MERCALLI INTENSITY SCALE 7

Table 1. Modified Mercalli Intensity Scale of 1931 (Abridged; Wood and Neumann, 1931, p. 282-283). As noted in the present text, some of the following criteria that describe human reactions or effects due to ground failure are no longer given significant influence in the assigning of intensity values.

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroye ctures destroyed with foundations; ground badly cracked. Rails bent. Landslides consid ep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

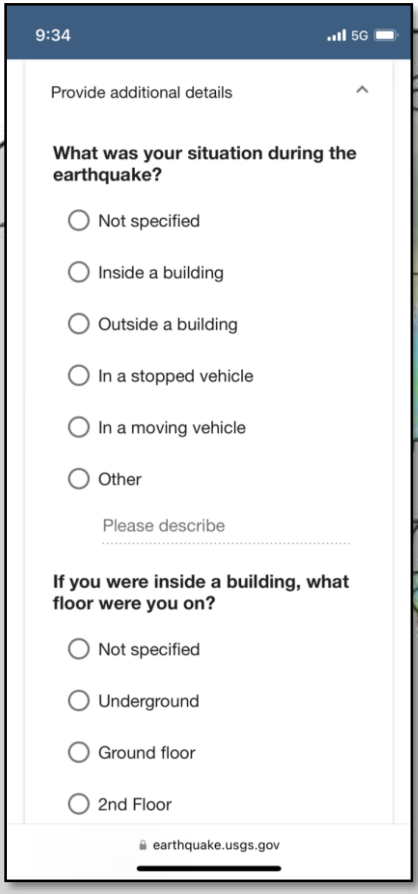
— POSSIBLE —

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps

XII. Damage total. Waves seen on ground jects thrown upward into the air.

— NO LONGER USED —

"Did You Feel It?" (DYFI)



9:34

Provide additional details

What was your situation during the earthquake?

- ○ Not specified
- ○ Inside a building
- ○ Outside a building
- ○ In a stopped vehicle
- ○ In a moving vehicle
- ○ Other

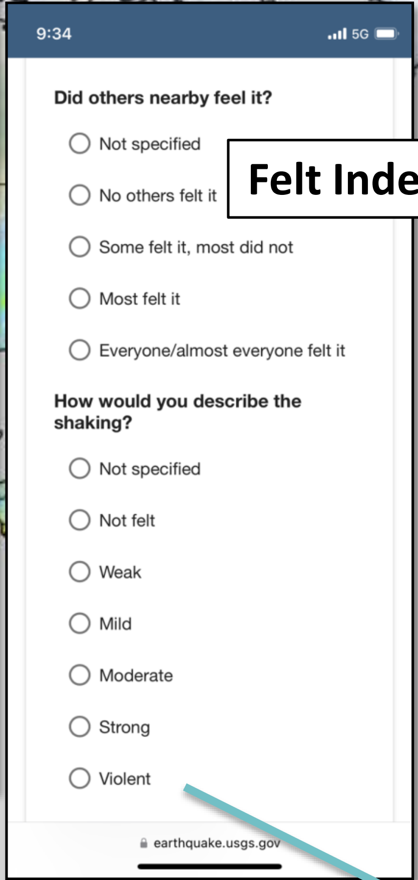
Please describe

If you were inside a building, what floor were you on?

- ○ Not specified
- ○ Underground
- ○ Ground floor
- ○ 2nd Floor

earthquake.usgs.gov

Felt Index



9:34

Did others nearby feel it?

- ○ Not specified
- ○ No others felt it
- ○ Some felt it, most did not
- ○ Most felt it
- ○ Everyone/almost everyone felt it

How would you describe the shaking?

- ○ Not specified
- ○ Not felt
- ○ Weak
- ○ Mild
- ○ Moderate
- ○ Strong
- ○ Violent

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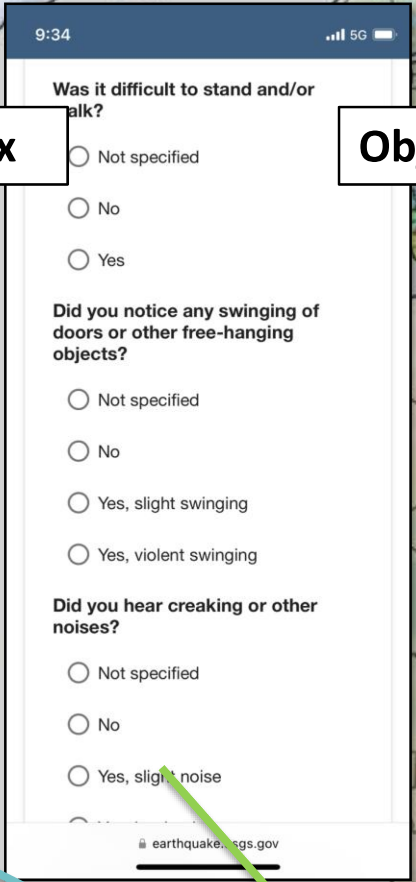


9:34

Was it difficult to stand and/or alk?

- ○ Not specified
- ○ No
- ○ Yes

Did you notice any swinging of doors or other free-hanging objects?

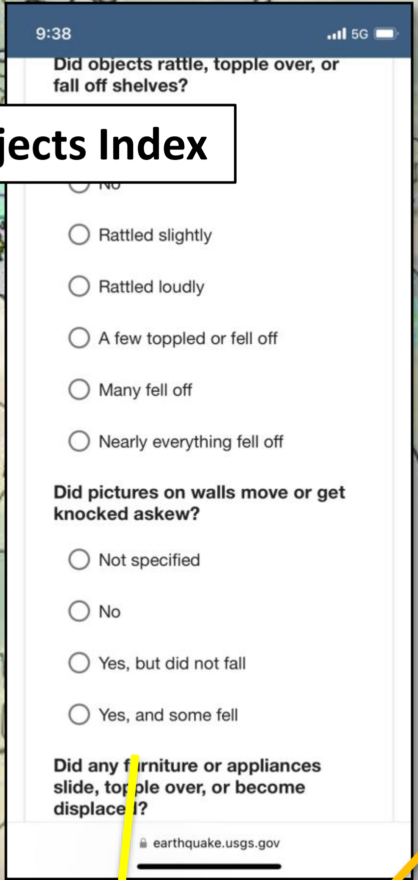
- ○ Not specified
- ○ No
- ○ Yes, slight swinging
- ○ Yes, violent swinging

Did you hear creaking or other noises?

- ○ Not specified
- ○ No
- ○ Yes, slight noise

earthquake.usgs.gov

Objects Index



9:38

Did objects rattle, topple over, or fall off shelves?

- ○ No
- ○ Rattled slightly
- ○ Rattled loudly
- ○ A few toppled or fell off
- ○ Many fell off
- ○ Nearly everything fell off

Did pictures on walls move or get knocked askew?

- ○ Not specified
- ○ No
- ○ Yes, but did not fall
- ○ Yes, and some fell

Did any furniture or appliances slide, topple over, or become displaced?

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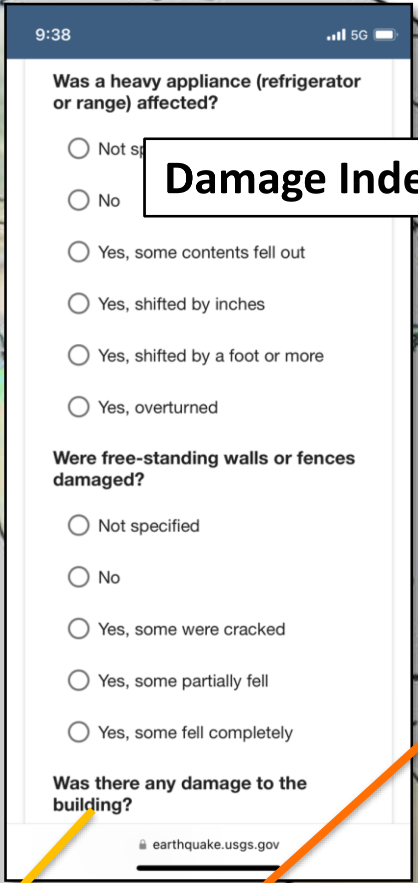
Damage Index



9:38

Was a heavy appliance (refrigerator or range) affected?

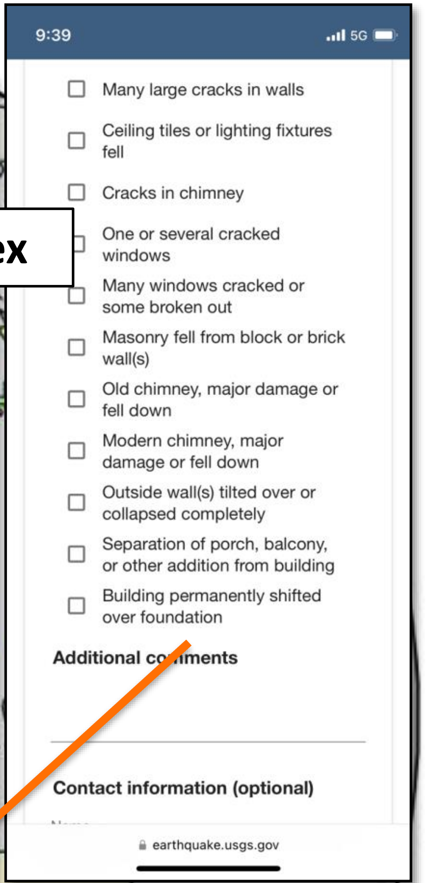
- ○ Not sp
- ○ No
- ○ Yes, some contents fell out
- ○ Yes, shifted by inches
- ○ Yes, shifted by a foot or more
- ○ Yes, overturned

Were free-standing walls or fences damaged?

- ○ Not specified
- ○ No
- ○ Yes, some were cracked
- ○ Yes, some partially fell
- ○ Yes, some fell completely

Was there any damage to the building?

earthquake.usgs.gov



9:39

- ☐ Many large cracks in walls
- ☐ Ceiling tiles or lighting fixtures fell
- ☐ Cracks in chimney
- ☐ One or several cracked windows
- ☐ Many windows cracked or some broken out
- ☐ Masonry fell from block or brick wall(s)
- ☐ Old chimney, major damage or fell down
- ☐ Modern chimney, major damage or fell down
- ☐ Outside wall(s) tilted over or collapsed completely
- ☐ Separation of porch, balcony, or other addition from building
- ☐ Building permanently shifted over foundation

Additional comments

Contact information (optional)

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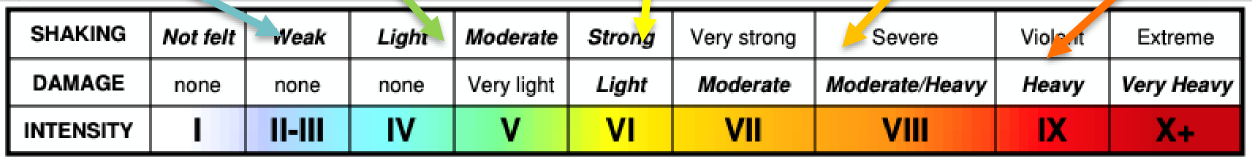
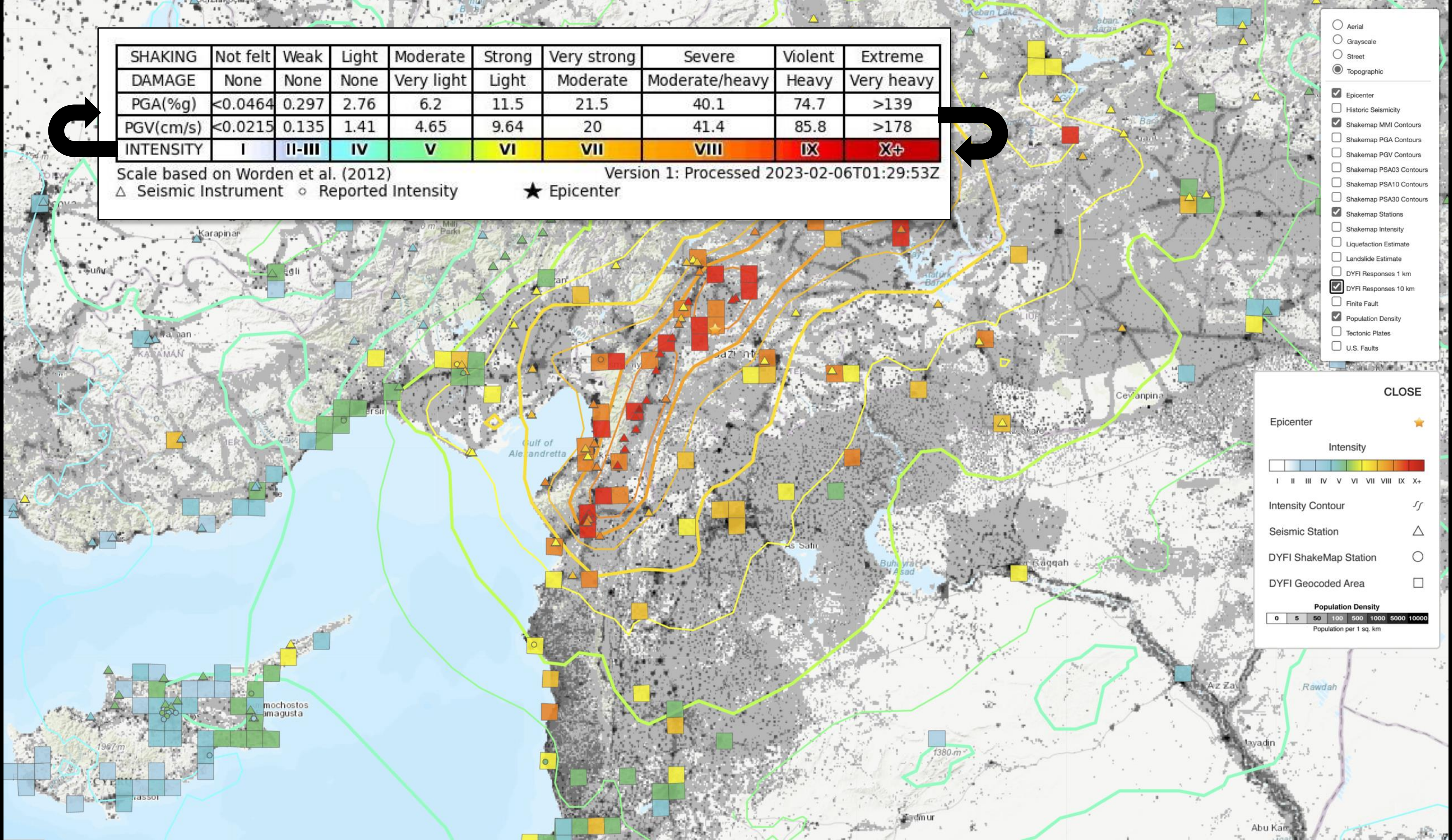
Maximum DYFI Intensity (2000 – 2022)
> 7 million responses



SHAKING	*Not felt*	*Weak*	*Light*	*Moderate*	*Strong*	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	*Light*	*Moderate*	*Moderate/Heavy*	*Heavy*	*Very Heavy*
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012)

Version 1: Processed 2023-02-06T01:29:53Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter

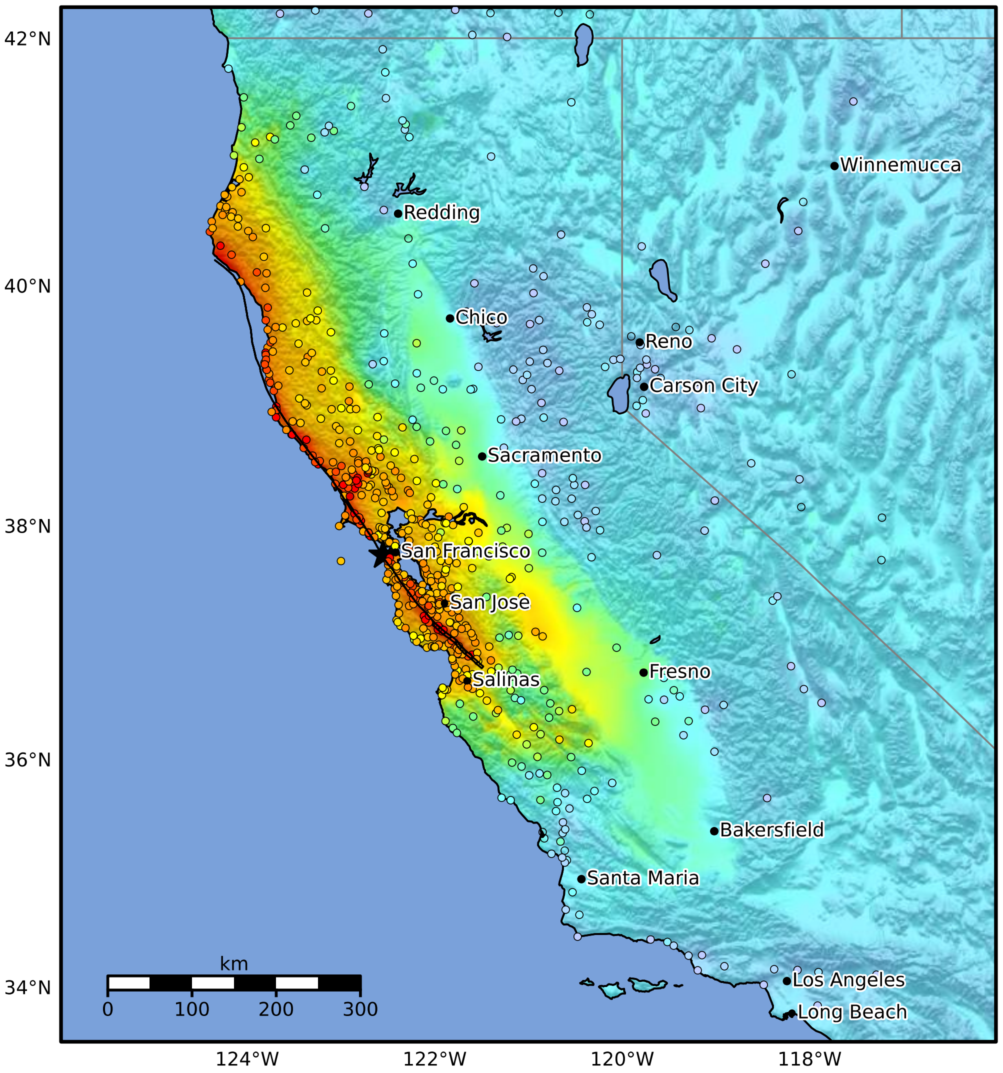
○ Aerial
○ Grayscale
○ Street
● Topographic

☑ 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
☐ Finite Fault
☑ Population Density
☐ Tectonic Plates
☐ U.S. Faults

CLOSE

Epicenter	★
Intensity Contour	∫
Seismic Station	△
DYFI ShakeMap Station	○
DYFI Geocoded Area	☐

1906 Great San Francisco Earthquake (M7.8)



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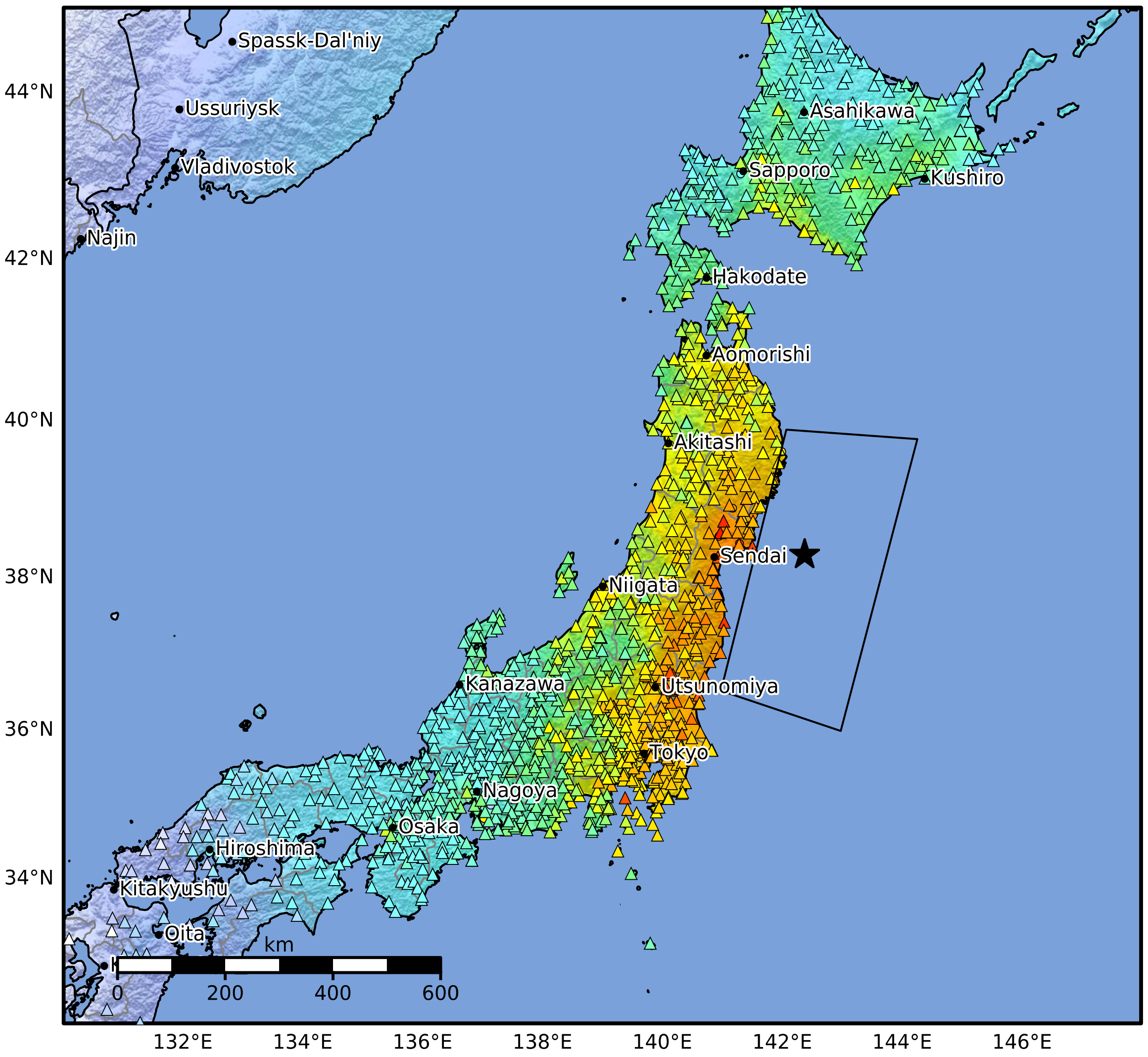
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 7: Processed 2020-04-03T16:25:01Z

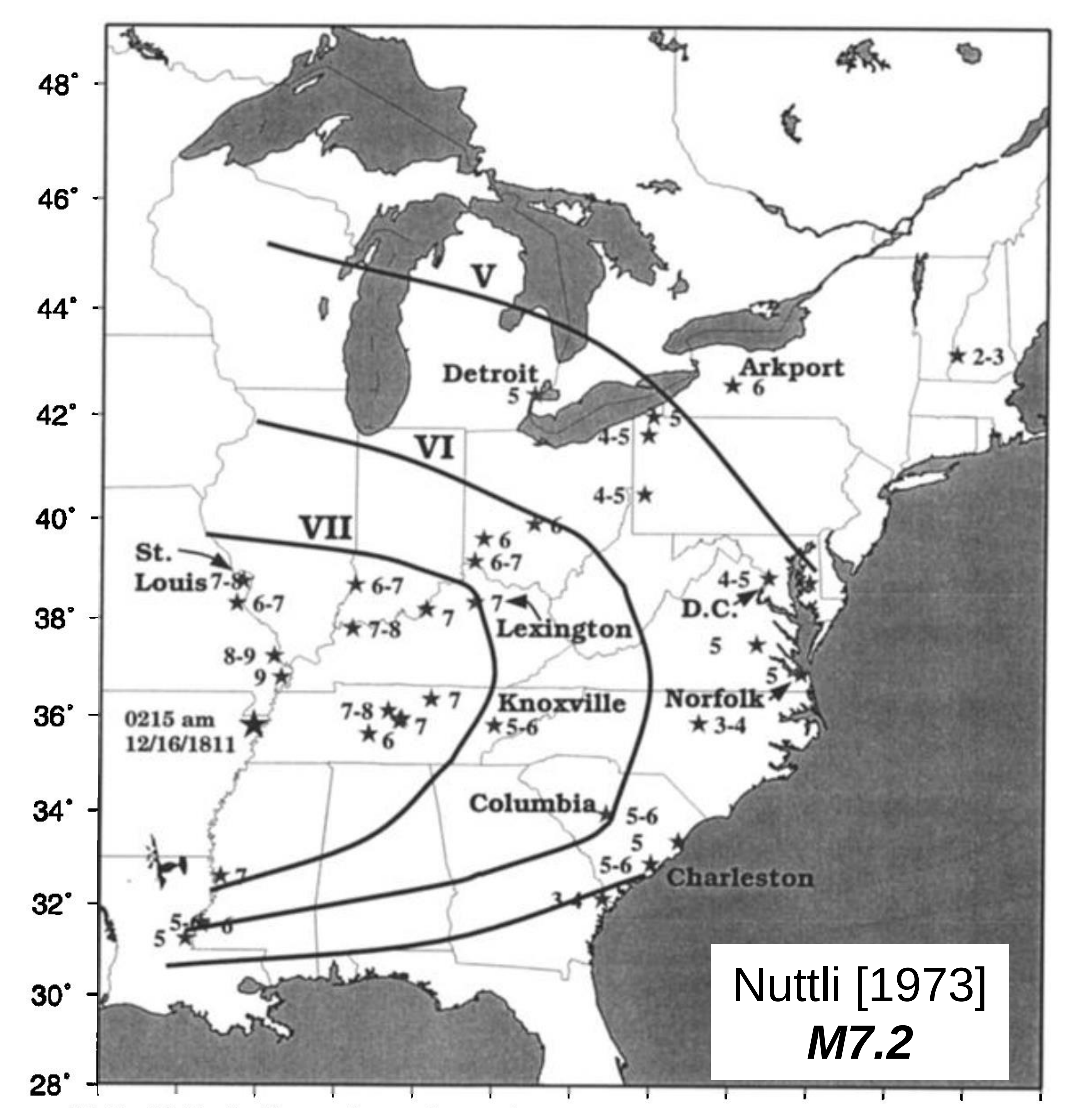
△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

2011 Tohoku, Japan Earthquake (M9.1)

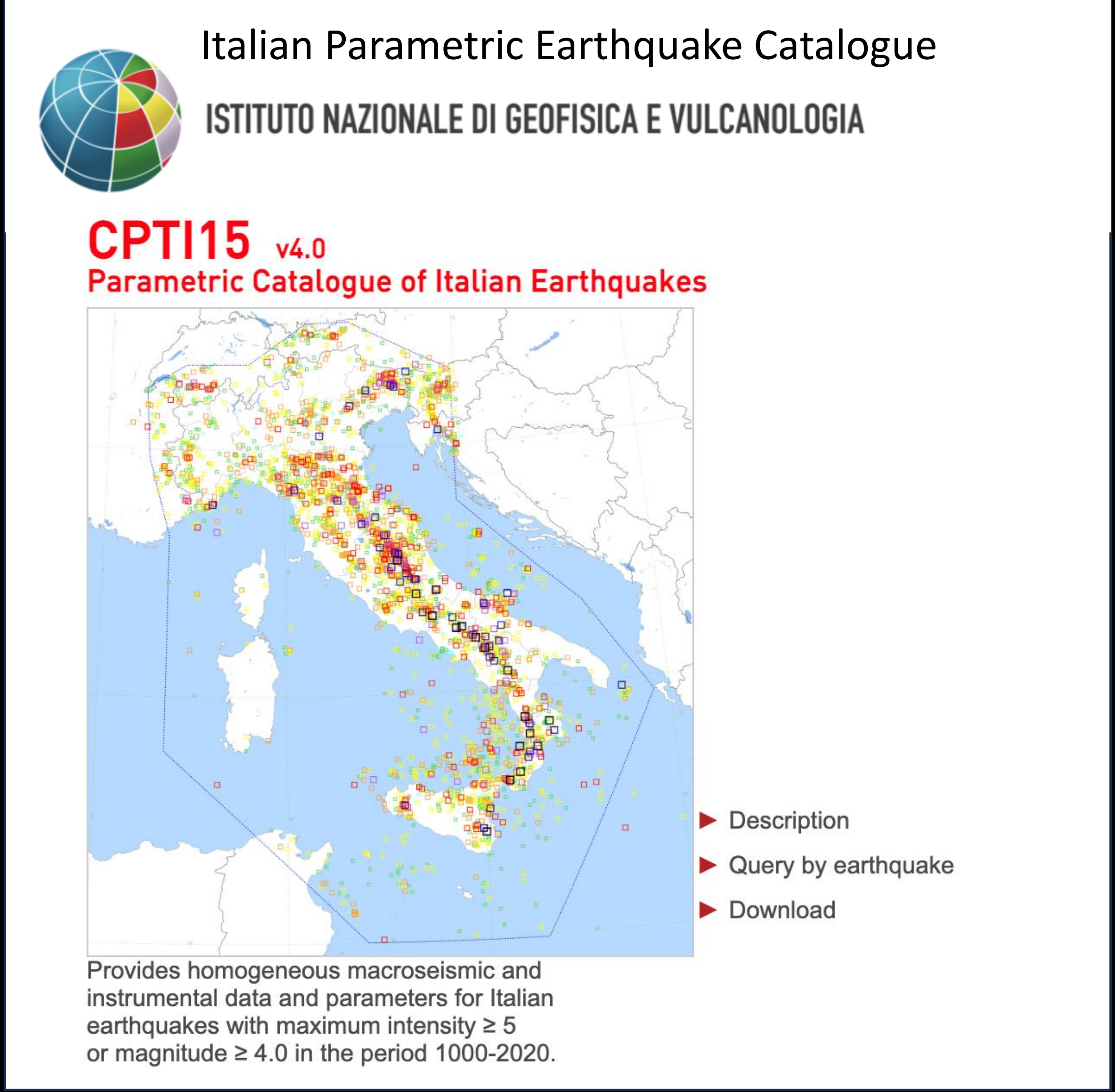


△ Seismic Instrument ○ Reported Intensity

Macroseismology & Historical Earthquakes



Nuttli [1973]
M7.2



Italian Parametric Earthquake Catalogue

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

CPTI15 v4.0

Parametric Catalogue of Italian Earthquakes

- ▶ Description
- ▶ Query by earthquake
- ▶ Download

Provides homogeneous macroseismic and instrumental data and parameters for Italian earthquakes with maximum intensity ≥ 5 or magnitude ≥ 4.0 in the period 1000-2020.

Macroseismology & Historical Earthquakes

Historical magnitudes & locations from:

- Felt area, or area (A) of a specific intensity level (say IV)

  $$\text{Log}(Mo)=18.53+0.823\ \text{Log}\ (A_{IV}) + \text{sqrt}(A_{IV})$$

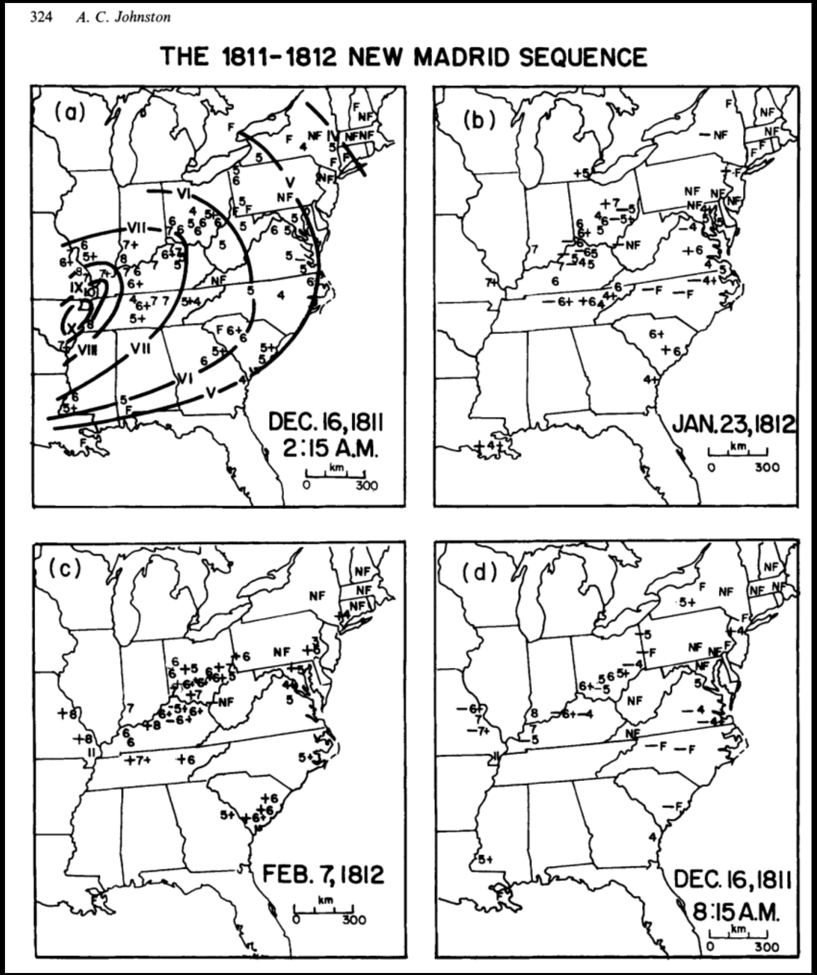
- I_o (epicentral intensity)

  $$Mw = 0.682\ I_o + 0.16$$

- Comparison with attenuation of modern events
- Shaking centroid from various inversion schemes:
  - Boxer (Gasparini et al)
  - Bakun & Wentworth

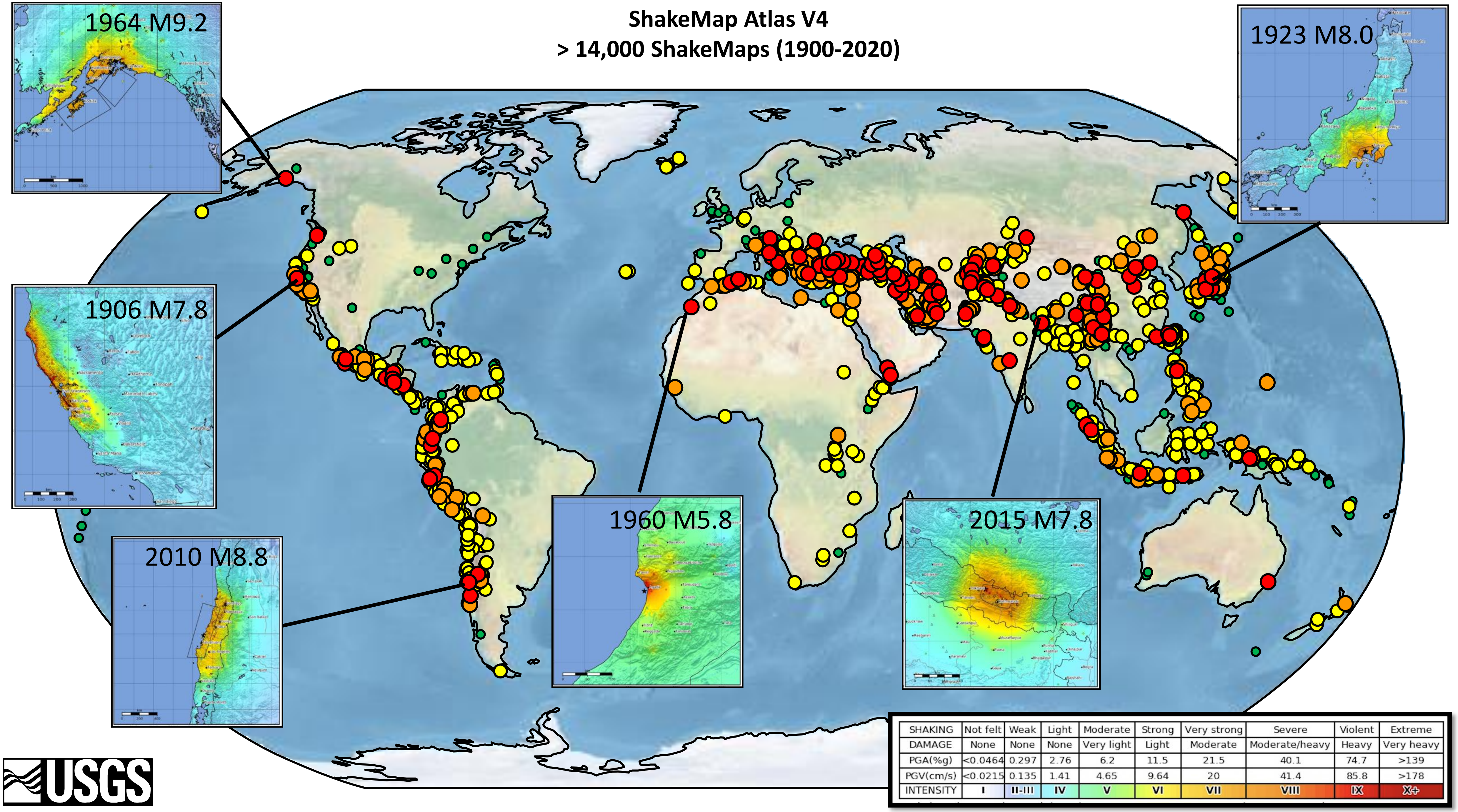
Challenges:

- Historical intensity assignments often ambiguous
- inaccurate locations; higher uncertainty
- Potentially biased due to selective reporting



Arch Johnston, 1993

ShakeMap Atlas V4
> 14,000 ShakeMaps (1900-2020)



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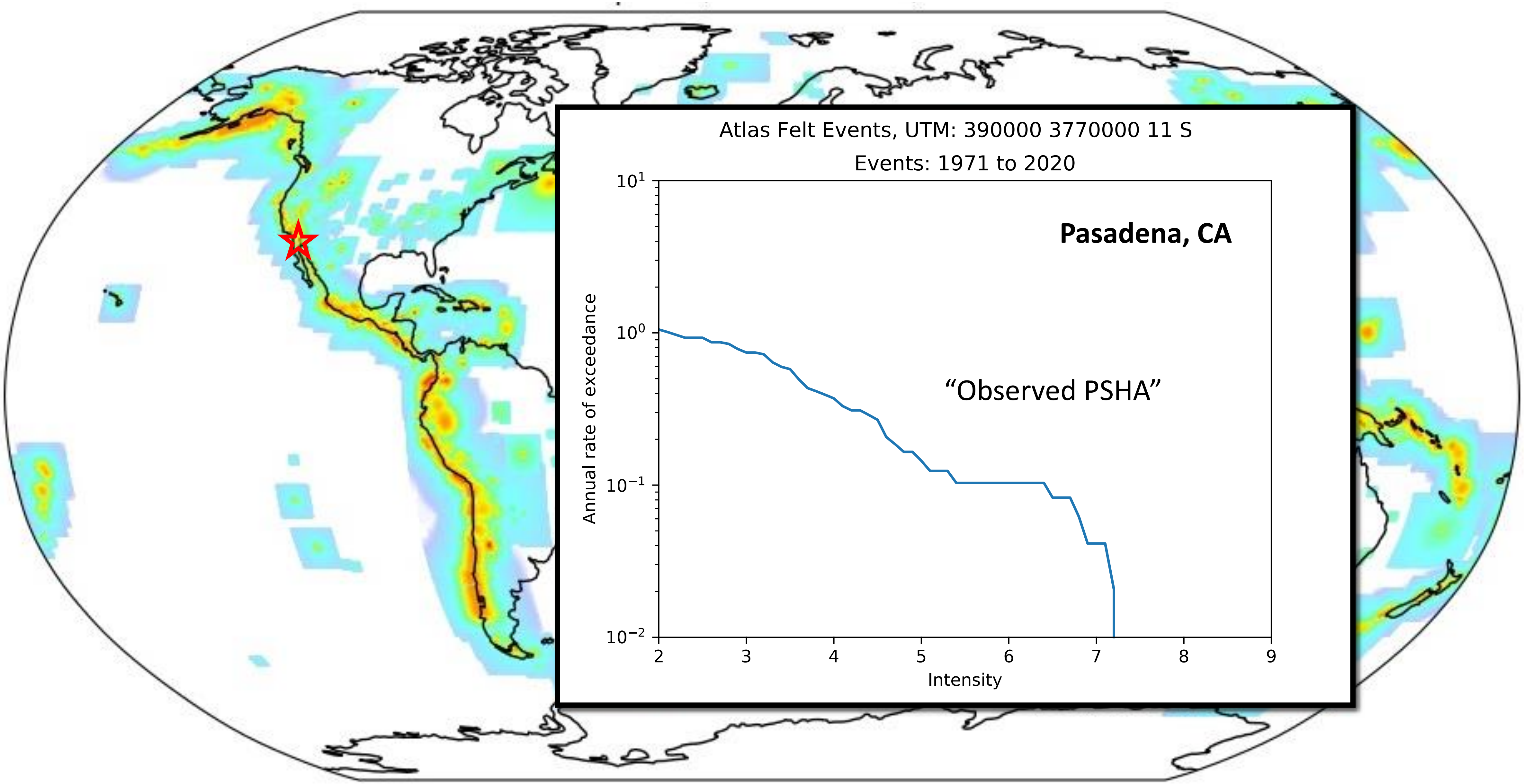
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Composite ShakeMap (Max. Shaking) Atlas V4 (1900-2020)



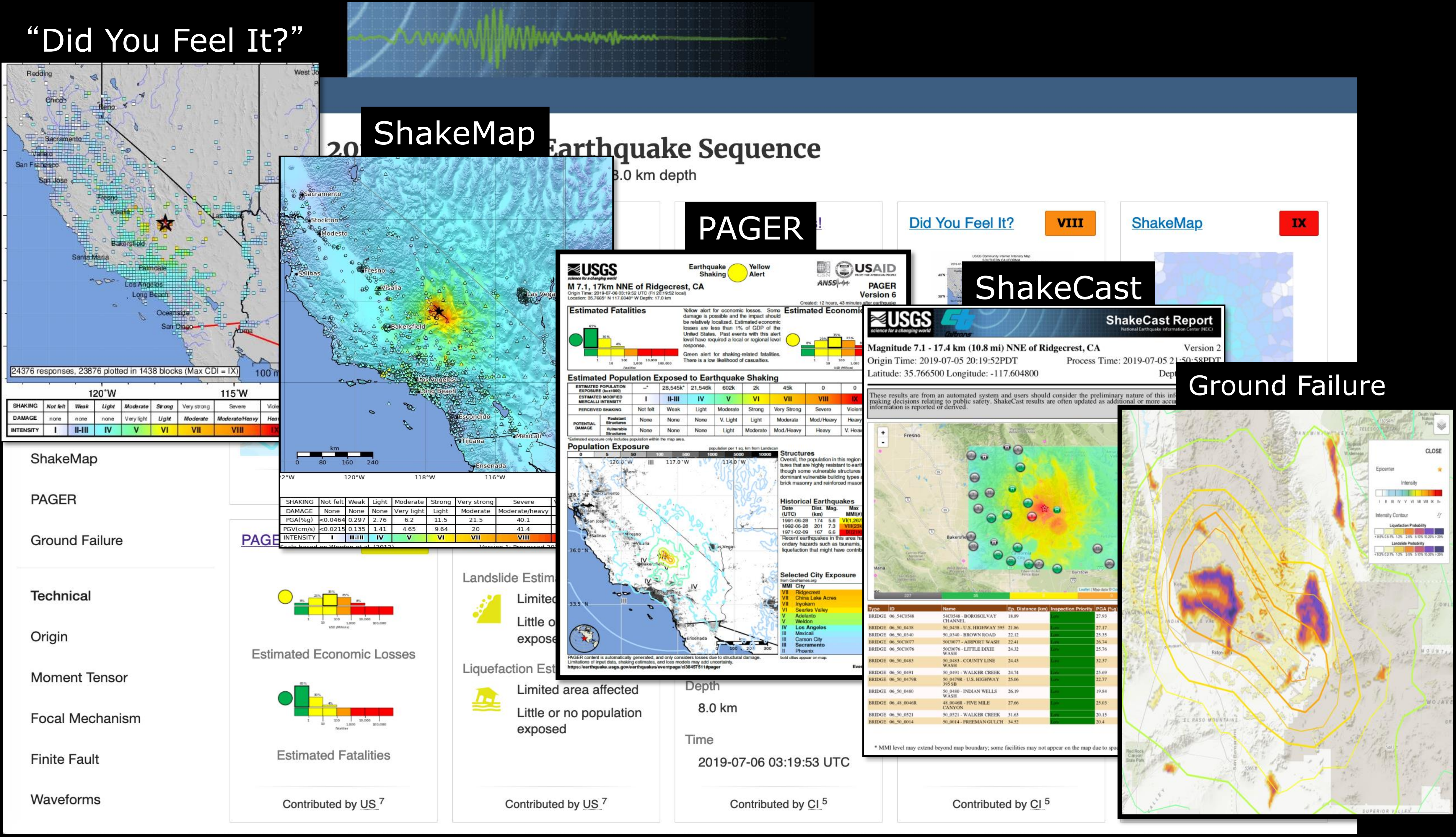
"Did You Feel It?"

ShakeMap

PAGER

ShakeCast

Ground Failure



20… Earthquake Sequence

…8.0 km depth

ShakeMap

PAGER

Ground Failure

Technical

Origin

Moment Tensor

Focal Mechanism

Finite Fault

Waveforms

Did You Feel It? VIII

ShakeMap IX

PAGE…

Estimated Economic Losses

Estimated Fatalities

Contributed by US 7

Landslide Estim…

Limited…

Little o… expose…

Liquefaction Est…

Limited area affected

Little or no population exposed

Contributed by US 7

Depth

8.0 km

Time

2019-07-06 03:19:53 UTC

Contributed by CI 5

Contributed by CI 5

24376 responses, 23876 plotted in 1438 blocks (Max CDI = IX)

SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Viole…
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Hea…
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX

SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy
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PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4
INTENSITY	I	II-III	IV	V	VI	VII	VIII

USGS Earthquake Shaking Yellow Alert — USAID — PAGER Version 6

M 7.1, 17km NNE of Ridgecrest, CA

Origin Time: 2019-07-06 03:19:52 UTC (Fri 20:19:52 local)

Location: 35.7665° N 117.6048° W Depth: 17.0 km

Estimated Fatalities

Yellow alert for economic losses. Some damage is possible and the impact should be relatively localized. Estimated economic losses are less than 1% of GDP of the United States. Past events with this alert level have required a local or regional level response.

Green alert for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Economic…

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k=x1000)	--*	28,545k*	21,546k	602k	2k	45k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent
POTENTIAL DAMAGE Resistant Structures	None	None	None	V. Light	Light	Moderate	Mod./Heavy	Heavy
POTENTIAL DAMAGE Vulnerable Structures	None	None	None	Light	Moderate	Mod./Heavy	Heavy	V. Heavy

Population Exposure

Structures

Historical Earthquakes

Selected City Exposure

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.

USGS ShakeCast Report

Magnitude 7.1 - 17.4 km (10.8 mi) NNE of Ridgecrest, CA Version 2

Origin Time: 2019-07-05 20:19:52PDT Process Time: 2019-07-05 21:50:58PDT

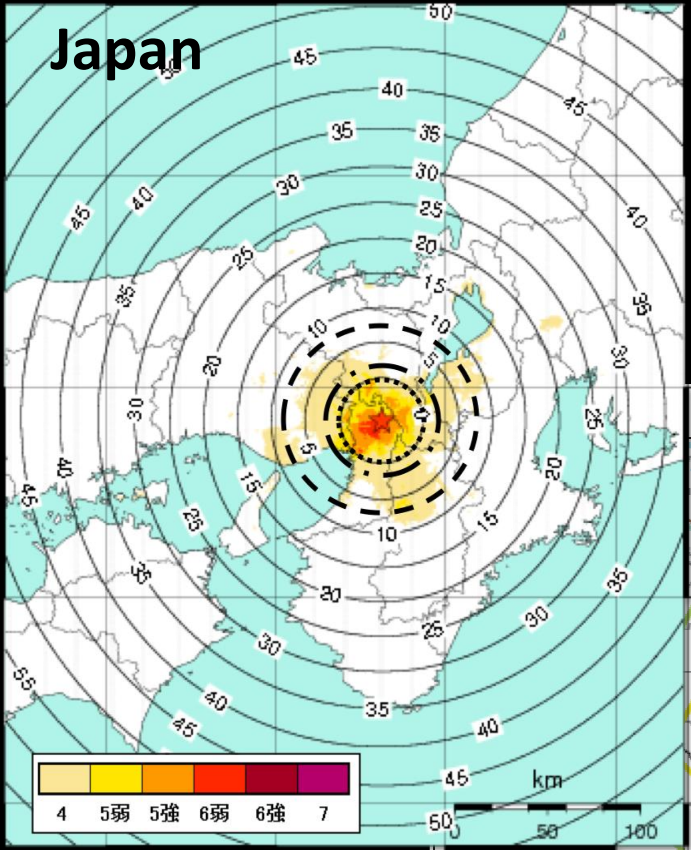
Latitude: 35.766500 Longitude: -117.604800

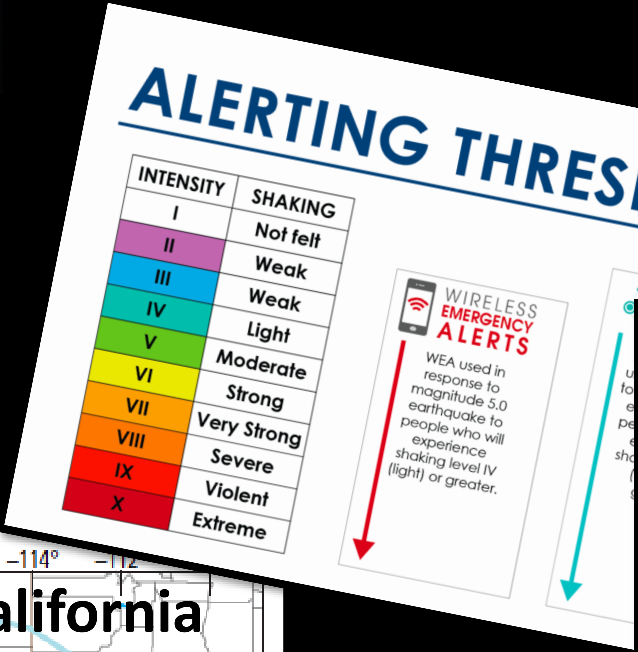
These results are from an automated system and users should consider the preliminary nature of this inf… making decisions relating to public safety. ShakeCast results are often updated as additional or more accu… information is reported or derived.

Type	ID	Name	Ep. Distance (km)	Inspection Priority	PGA (%g)
BRIDGE	06_54C0548	54C0548 - BOROSOLVAY CHANNEL	18.89	Low	27.93
BRIDGE	06_50_0438	50_0438 - U.S. HIGHWAY 395	21.86	Low	27.17
BRIDGE	06_50_0340	50_0340 - BROWN ROAD	22.12	Low	25.35
BRIDGE	06_50C0077	50C0077 - AIRPORT WASH	22.41	Low	26.74
BRIDGE	06_50C0076	50C0076 - LITTLE DIXIE WASH	24.32	Low	25.76
BRIDGE	06_50_0483	50_0483 - COUNTY LINE WASH	24.43	Low	32.37
BRIDGE	06_50_0491	50_0491 - WALKER CREEK	24.74	Low	25.69
BRIDGE	06_50_0479R	50_0479R - U.S. HIGHWAY 395 SB	25.06	Low	22.77
BRIDGE	06_50_0480	50_0480 - INDIAN WELLS WASH	26.19	Low	19.84
BRIDGE	06_48_0046R	48_0046R - FIVE MILE CANYON	27.66	Low	25.03
BRIDGE	06_50_0521	50_0521 - WALKER CREEK	31.63	Low	20.15
BRIDGE	06_50_0014	50_0014 - FREEMAN GULCH	34.52	Low	20.4

* MMI level may extend beyond map boundary; some facilities may not appear on the map due to spa…

Use of intensity in triggering & communicating EEW


Japan

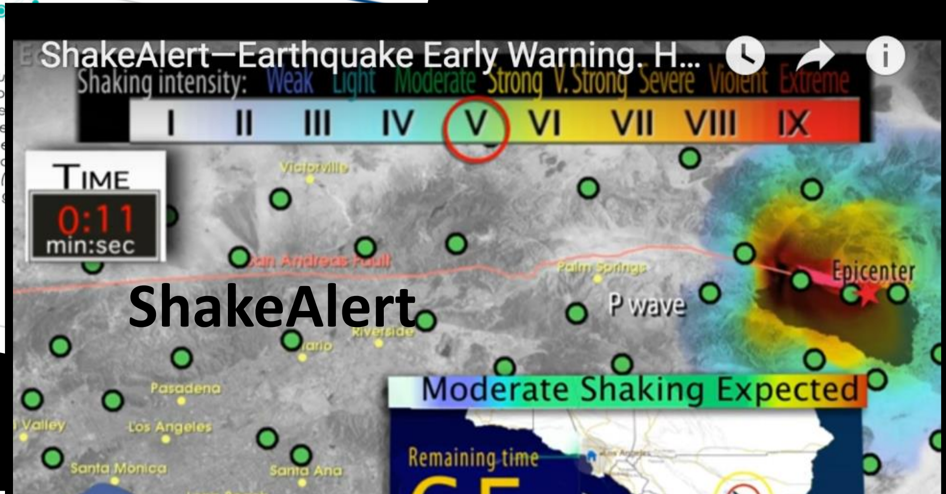

ALERTING THRESHOLDS

INTENSITY	SHAKING
I	Not felt
II	Weak
III	Weak
IV	Light
V	Moderate
VI	Strong
VII	Very Strong
VIII	Severe
IX	Violent
X	Extreme

WIRELESS EMERGENCY ALERTS

WEA used in response to magnitude 5.0 earthquake to people who will experience shaking level IV (light) or greater.

Cal OES GOVERNOR'S OFFICE OF EMERGENCY SERVICES


ShakeAlert—Earthquake Early Warning. H...

Shaking intensity: Weak Light Moderate Strong V.Strong Severe Violent Extreme

I II III IV V VI VII VIII IX

TIME 0:11 min:sec

Moderate Shaking Expected

Remaining time 65

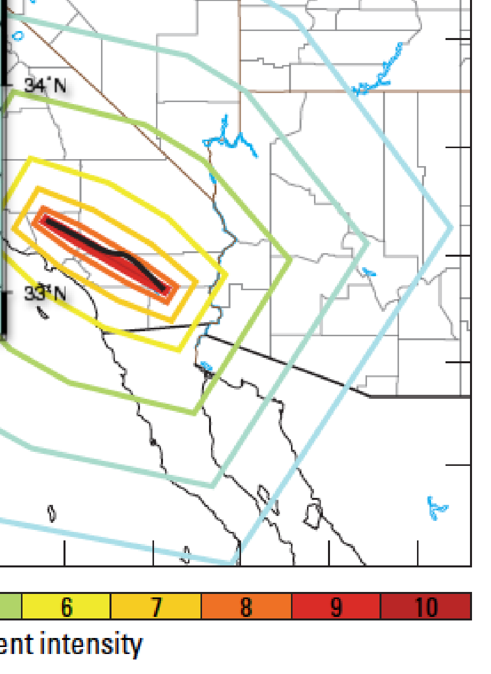
Expected Intensity V

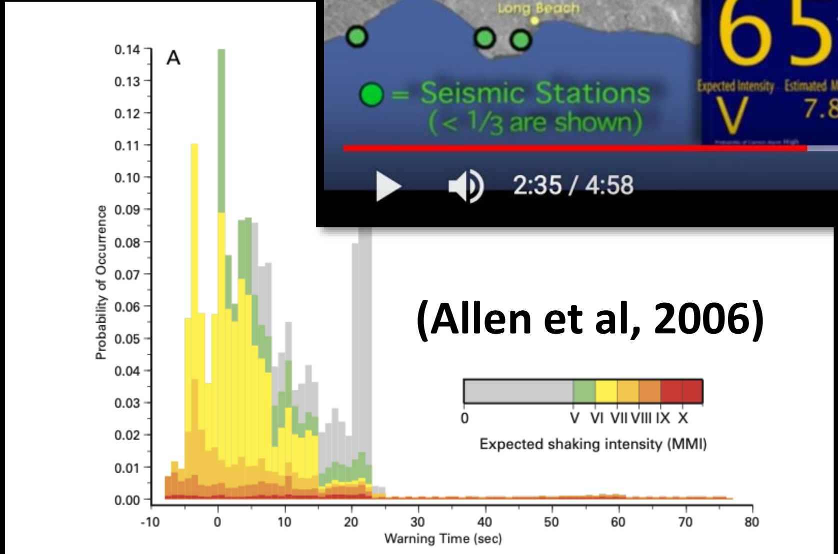
Estimated Magnitude 7.8 Magnitude

● = Seismic Stations (< 1/3 are shown)

2:35 / 4:58

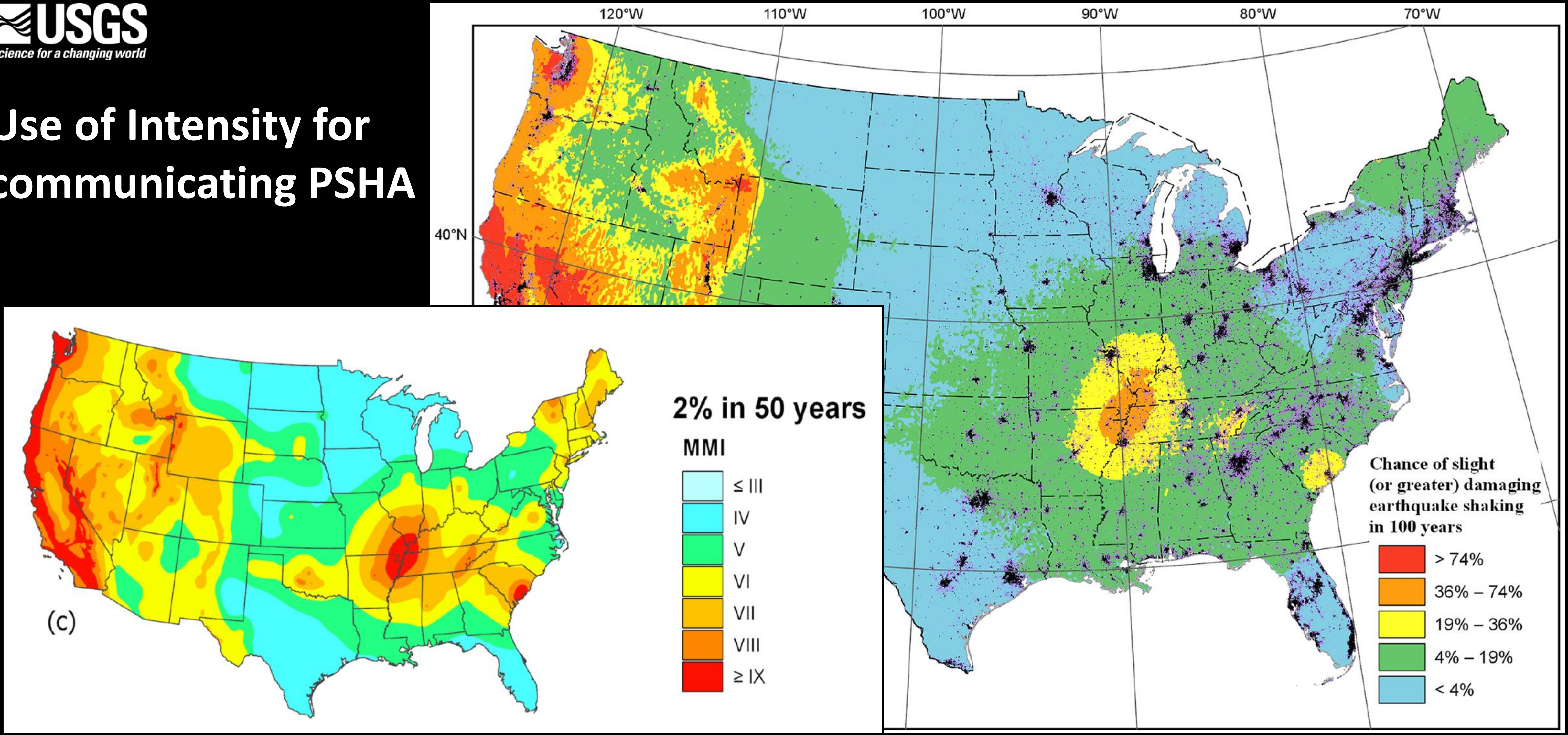
ShakeAlert


California



(Allen et al, 2006)

Use of Intensity for communicating PSHA



Map showing the chance of minor damaging shaking in 100 years from the 2018 NSHM.
[From Petersen et al., 2019, *Earthquake Spectra*]

“We believe that macroseismic scales are not static, but they instead should be updated on the basis of new experimental observations.” (Patricia Tosi et al., 2015).

Modified Mercalli Intensity (MMI) is outmoded

- USGS no longer uses ground changes as indicators.
- Chimney damage—a key indicator in the US/NZ—less useful these days.
- MMI >= IX difficult to assign (requires opinion, rather than quantitative assignment). This makes it difficult to use high MMIs quantitatively.

USGS-sponsored Powell Center Workshop
Fort Collins, Colorado, Oct 2022

(1) Revise the MMI scale in United States and New Zealand to be compatible with EMS-98,

(2) Improve US/NZ strategies for rapid macroseismic assignments, particularly for higher intensities, and

(3) Align these revisions into recommendations & contributions towards an an IMS.

Principal Investigators:

David Wald, USGS

Tatiana Goded, GNS Science

Ayse Hortacsu, Applied Technology Council

Robin Spence, Cambridge Architectural Research

Developing and Implementing an International Macroseismic Scale (IMS) for Earthquake Engineering, Earthquake Science, and Rapid Damage Assessment

ACTIVE

By John Wesley Powell Center for Analysis and Synthesis September 30, 2020

The USGS “Did You Feel It” (DYFI) is an extremely popular way for members of the public to contribute to earthquake science and earthquake response. DYFI has been in operation for nearly two decades (1999-2019) in the U.S., and for nearly 15 years globally. During that period the amount of data collected is astounding: Over 5 million individual DYFI intensity reports—spanning all magnitude and distance ranges—have been amassed and archived. Several of these types of surveys have been developed by international seismological institutions as well and many of these institutions have implemented algorithms to interpret intensity evaluations automatically, as a rapid and easy way to obtain a geographical distribution of the damage.

However, these automatic intensity evaluations have a known limitation: they are best for assigning intensity values up to VII in the case of the US and New Zealand MMI. At MMI VII and above, buildings can suffer considerable damage, and the assignment of intensity values requires engineers’ involvement to assess the building’s type and damage level. In the US, the USGS considers that intensities VIII and higher should be evaluated by professionals, so for destructive earthquakes, alternative macroseismic observations (e.g., from engineering reports, press reports and field reconnaissance) should be used. With the need to have seismologists and engineers review the higher intensity assignments, an unsolved problem is how to automatically evaluate and assign higher shaking intensities. We note that USGS *no longer maintains staff with macroseismic expertise dedicated to assigning intensities for future earthquakes.*

Moreover, MMI itself is a somewhat outmoded scale compared with the more recently developed system used in much of Europe (EMS-98), which allows for statistics of building damage and distributions. However, in the U.S. (and New Zealand, among other countries) our buildings are not represented in EMS-98, which was developed for Europe, so a globally applicable scale has not taken hold. The main aims of this project, then, are to (1) revise the MMI scale in

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Explore Search

Natural Hazards

All Working Groups

Other

European Macroseismic Intensity Scale (EMS-98)

G. Grunthal, GeoForschungsZentrum, Germany

R. Musson, British Geological Survey, Great Britain
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ACCORD PARTIEL OUVERT
en matière de prévention, de protection et
d'organisation des secours contre les risques naturels
et technologiques majeurs du

CONSEIL DE L'EUROPE
Cahiers
du Centre Européen
de Géodynamique
et de Séismologie

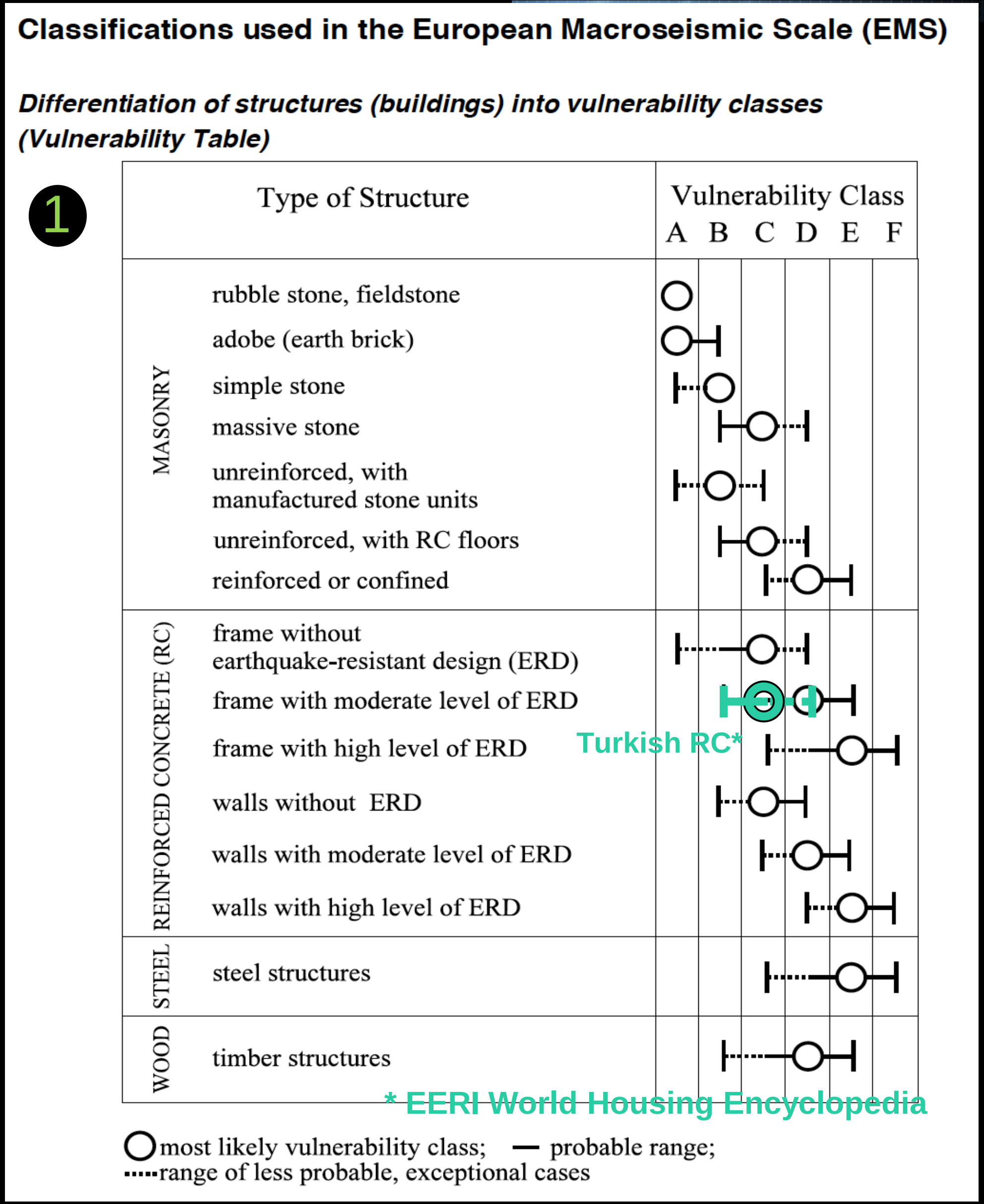
Volume 15

European Macroseismic Scale 1998

Editor
G. GRÜNTHAL

Luxembourg 1998

EMS-98 Ingredients…



①

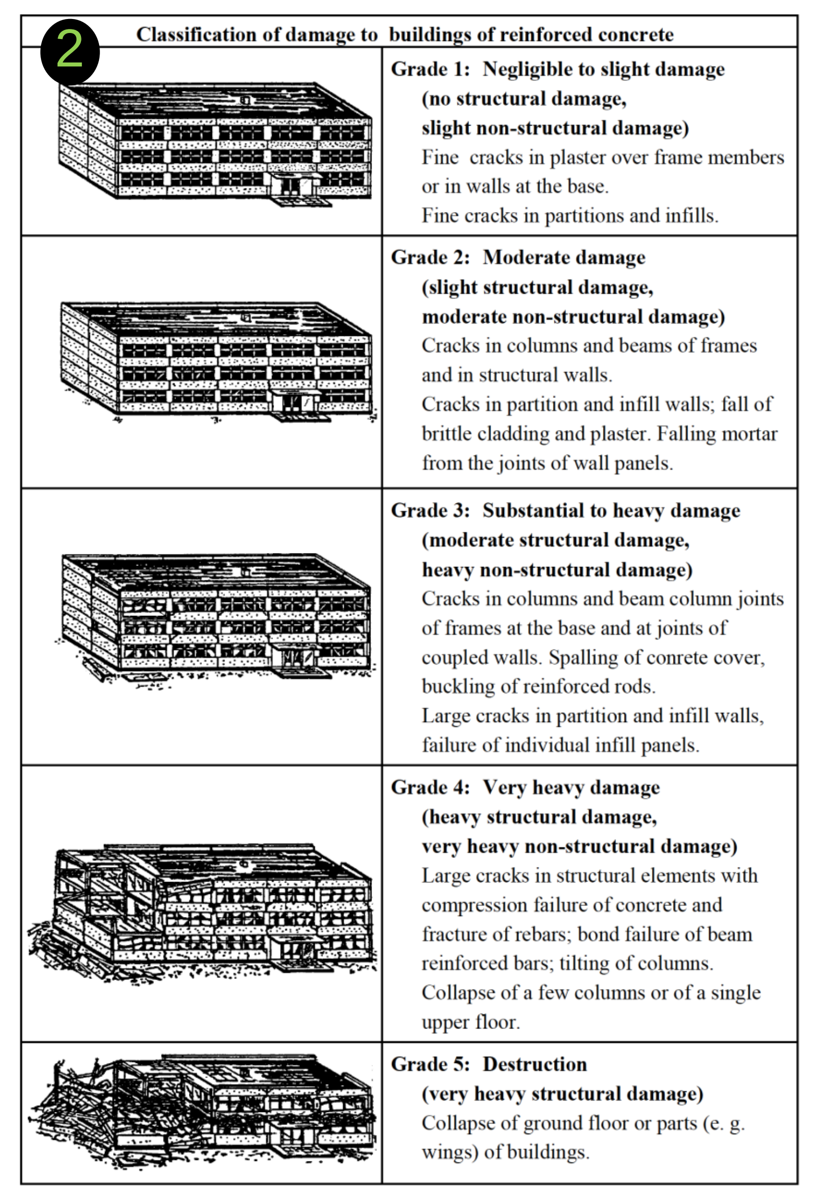
Classifications used in the European Macroseismic Scale (EMS)

Differentiation of structures (buildings) into vulnerability classes (Vulnerability Table)

	Type of Structure	A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	○					
	adobe (earth brick)	○	—				
	simple stone	┄	○				
	massive stone		—	○	┄		
	unreinforced, with manufactured stone units	┄	○	┄			
	unreinforced, with RC floors		—	○	┄		
	reinforced or confined			┄	○	—	
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	┄	—	○	┄		
	frame with moderate level of ERD		┄	—	○	—	
	Turkish RC*		—	○	—		
	frame with high level of ERD			┄	—	○	—
	walls without ERD		┄	○	—		
	walls with moderate level of ERD			┄	○	—	
	walls with high level of ERD				┄	○	—
STEEL	steel structures			┄	—	○	—
WOOD	timber structures		┄	—	○	—	

* EERI World Housing Encyclopedia

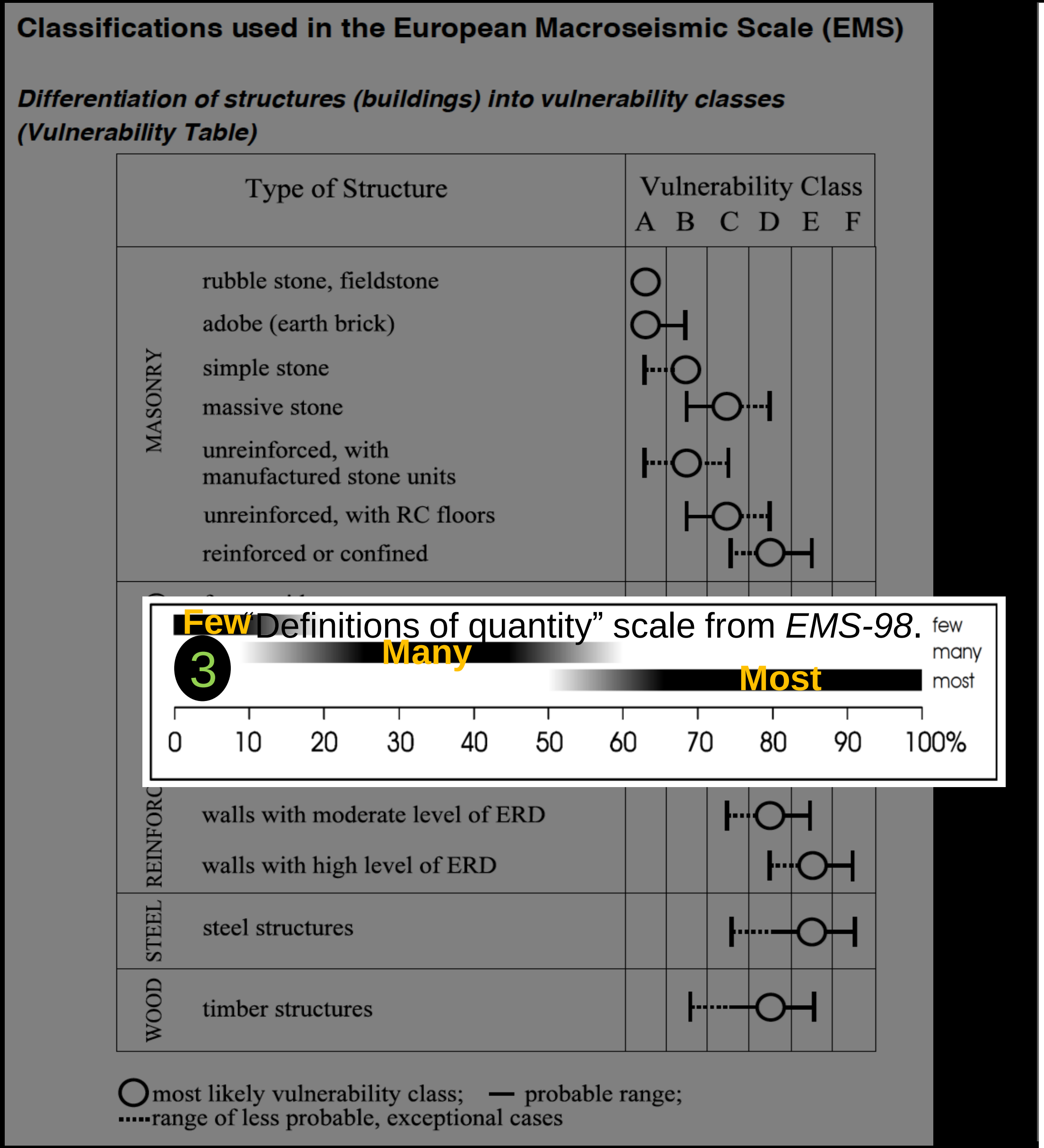
○ most likely vulnerability class; — probable range;
┄ range of less probable, exceptional cases



②

Classification of damage to buildings of reinforced concrete	
	Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage) Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	Grade 5: Destruction (very heavy structural damage) Collapse of ground floor or parts (e. g. wings) of buildings.

EMS-98 Ingredients…



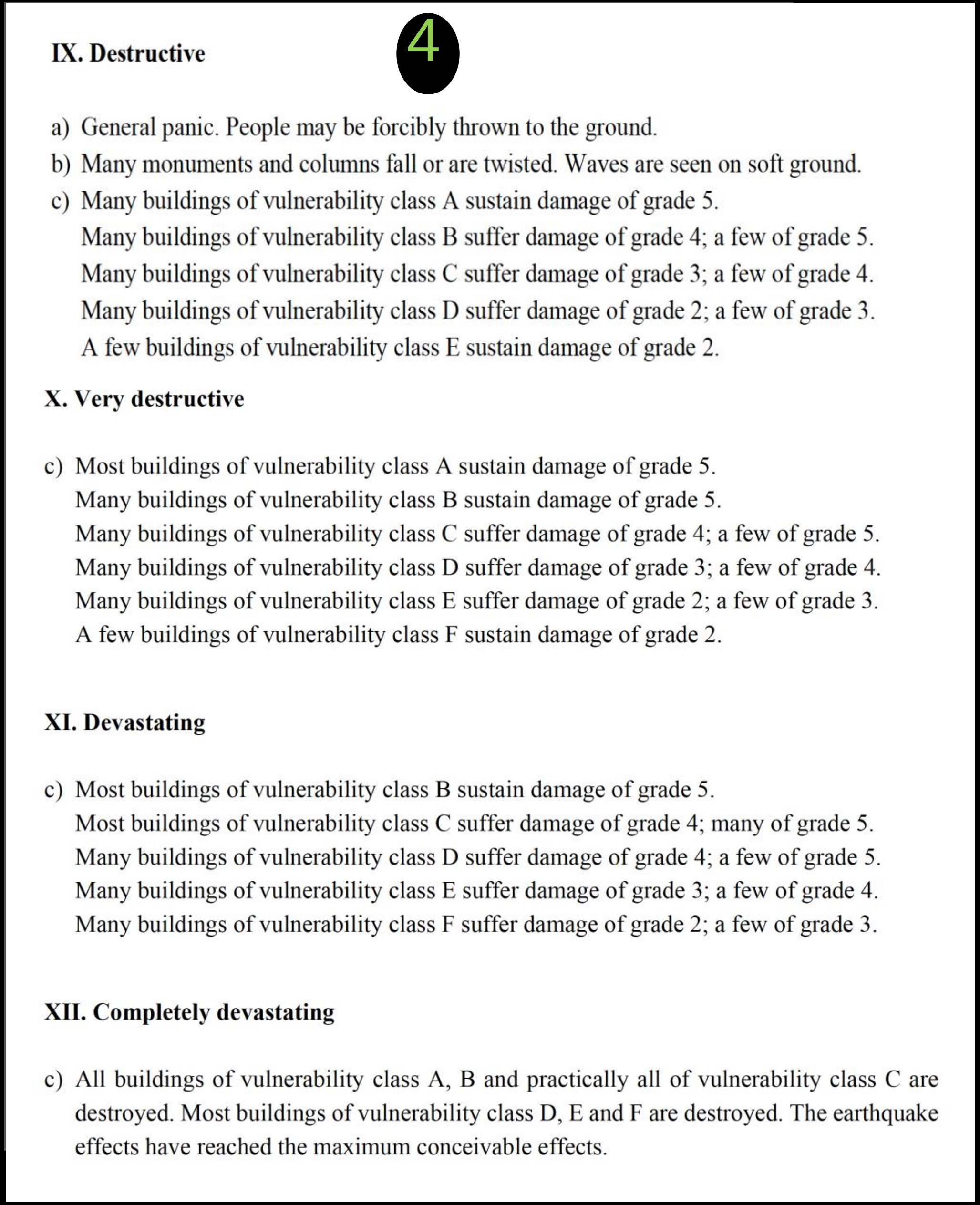
Classifications used in the European Macroseismic Scale (EMS)

Differentiation of structures (buildings) into vulnerability classes (Vulnerability Table)

	Type of Structure	A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	○					
	adobe (earth brick)	○	—				
	simple stone	·····	○				
	massive stone		—	○	·····		
	unreinforced, with manufactured stone units	·····	○	·····			
	unreinforced, with RC floors		—	○	·····		
	reinforced or confined			·····	○	—	
REINFORC	walls with moderate level of ERD			·····	○	—	
	walls with high level of ERD				·····	○	—
STEEL	steel structures			·····	·····	○	—
WOOD	timber structures		·····	·····	○	—	

○ most likely vulnerability class; — probable range;
····· range of less probable, exceptional cases

"Definitions of quantity" scale from *EMS-98*.



IX. Destructive

a) General panic. People may be forcibly thrown to the ground.

b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.

c) Many buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class C suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class D suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class E sustain damage of grade 2.

X. Very destructive

c) Most buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B sustain damage of grade 5.
Many buildings of vulnerability class C suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class D suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class E suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class F sustain damage of grade 2.

XI. Devastating

c) Most buildings of vulnerability class B sustain damage of grade 5.
Most buildings of vulnerability class C suffer damage of grade 4; many of grade 5.
Many buildings of vulnerability class D suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class E suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class F suffer damage of grade 2; a few of grade 3.

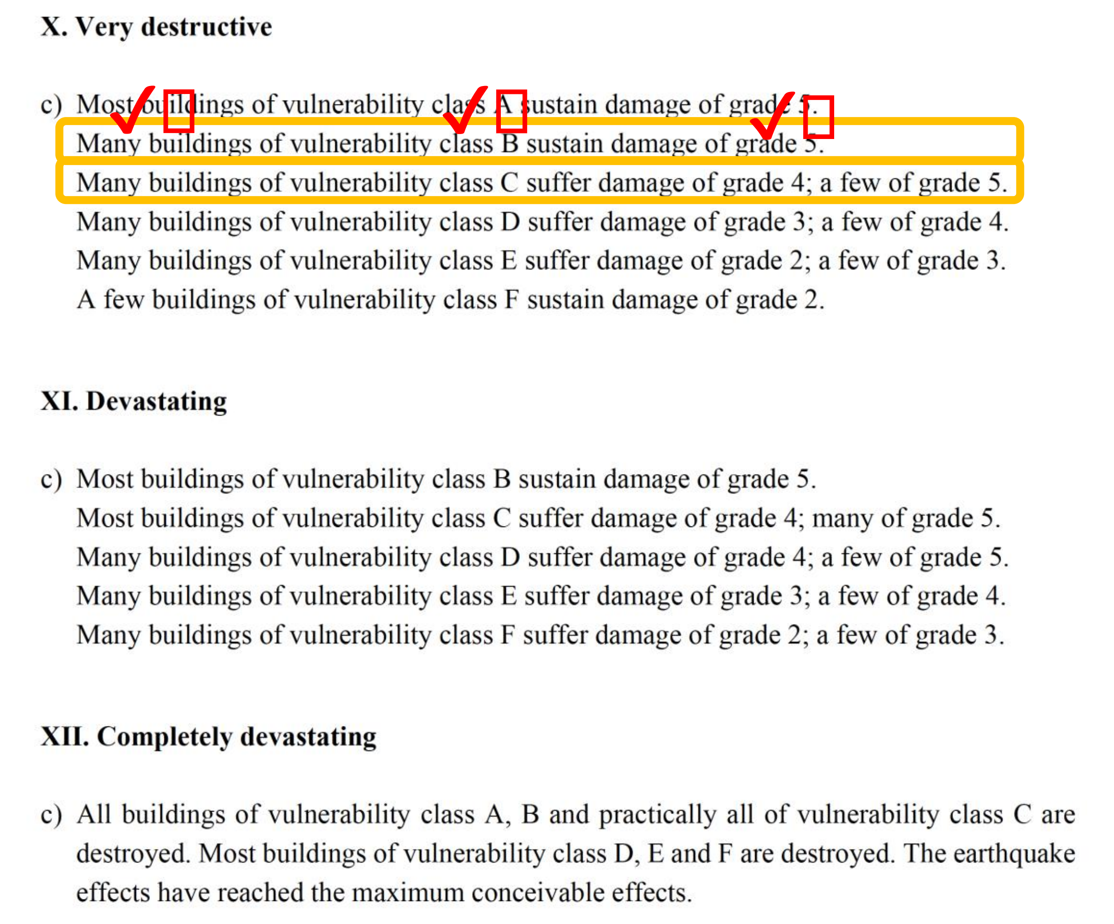
XII. Completely devastating

c) All buildings of vulnerability class A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability class D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

After Grunthal et al, EMS-98

Reinforced Concrete (RC) with masonry infill is EMS-98 Vulnerability Class B or C with Damage Grade 3,4,5

2023 M7.8 Turkiye, Earthquake
(Hatay location)



X. Very destructive

c) Most buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B sustain damage of grade 5.
Many buildings of vulnerability class C suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class D suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class E suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class F sustain damage of grade 2.

XI. Devastating

c) Most buildings of vulnerability class B sustain damage of grade 5.
Most buildings of vulnerability class C suffer damage of grade 4; many of grade 5.
Many buildings of vulnerability class D suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class E suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class F suffer damage of grade 2; a few of grade 3.

XII. Completely devastating

c) All buildings of vulnerability class A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability class D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

Photo credit: Gettyimages.com

Bull Earthquake Eng (2006) 4:415–443
DOI 10.1007/s10518-006-9024-z

ORIGINAL RESEARCH PAPER

Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings

Sergio Lagomarsino · **Sonia Giovinazzi**

Table 1 Proposal for a European building typology classification

Typologies	Building types
Unreinforced Masonry	M1 Rubble stone
	M2 Adobe (earth bricks)
	M3 Simple stone
	M4 Massive stone
	M5 U Masonry (old bricks)
	M6 U Masonry – r.c. floors
Reinforced/confined masonry	M7 Reinforced/confined masonry
Reinforced Concrete	RC1 Concrete Moment Frame
	RC2 Concrete Shear Walls
	RC3 Dual System

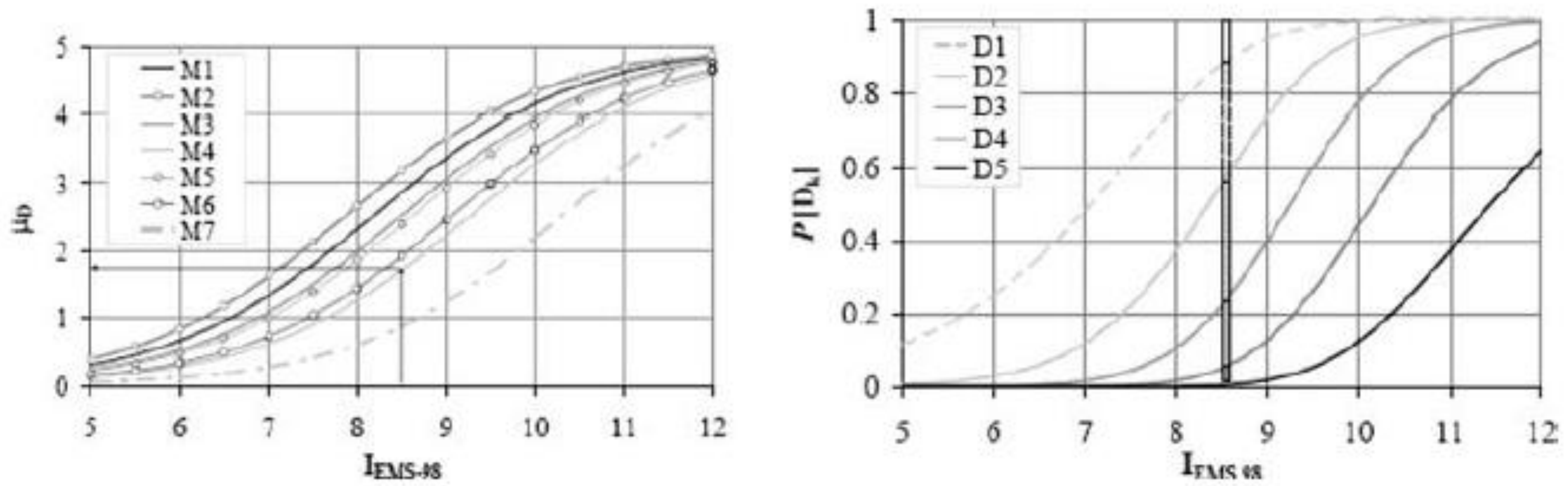
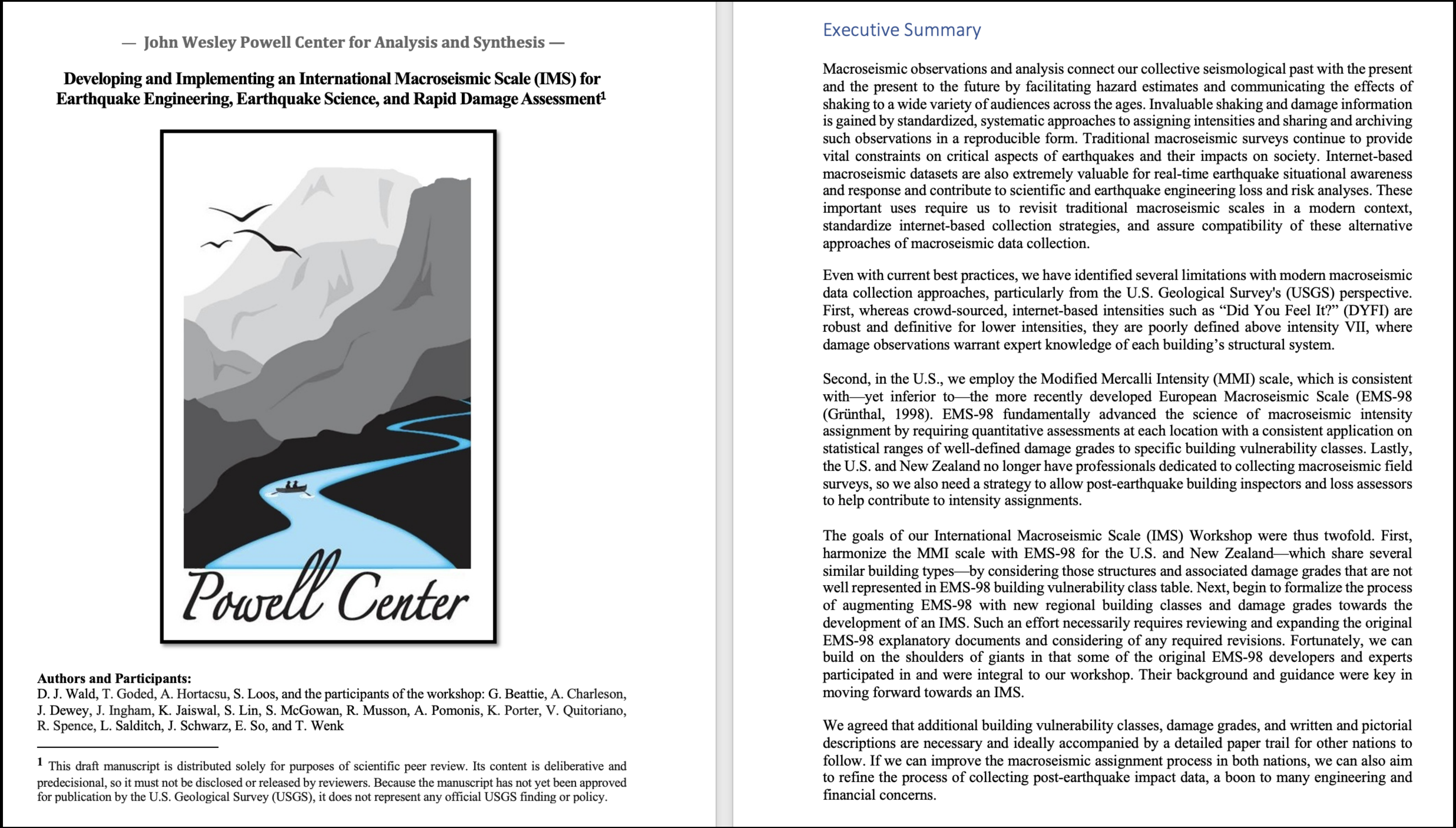


Fig. 1 Macroseismic method: **a** vulnerability curves for different masonry building typologies; expected damage $\mu_D = 1.7$ for M4 typology when $I = 8.5$, **b** fragility curves for the building typology M4 as a function of I; damage distribution for $I = 8.5$



— John Wesley Powell Center for Analysis and Synthesis —

Developing and Implementing an International Macroseismic Scale (IMS) for Earthquake Engineering, Earthquake Science, and Rapid Damage Assessment[1]

Authors and Participants:
D. J. Wald, T. Goded, A. Hortacsu, S. Loos, and the participants of the workshop: G. Beattie, A. Charleson, J. Dewey, J. Ingham, K. Jaiswal, S. Lin, S. McGowan, R. Musson, A. Pomonis, K. Porter, V. Quitoriano, R. Spence, L. Salditch, J. Schwarz, E. So, and T. Wenk

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[1] This draft manuscript is distributed solely for purposes of scientific peer review. Its content is deliberative and predecisional, so it must not be disclosed or released by reviewers. Because the manuscript has not yet been approved for publication by the U.S. Geological Survey (USGS), it does not represent any official USGS finding or policy.

Executive Summary

Macroseismic observations and analysis connect our collective seismological past with the present and the present to the future by facilitating hazard estimates and communicating the effects of shaking to a wide variety of audiences across the ages. Invaluable shaking and damage information is gained by standardized, systematic approaches to assigning intensities and sharing and archiving such observations in a reproducible form. Traditional macroseismic surveys continue to provide vital constraints on critical aspects of earthquakes and their impacts on society. Internet-based macroseismic datasets are also extremely valuable for real-time earthquake situational awareness and response and contribute to scientific and earthquake engineering loss and risk analyses. These important uses require us to revisit traditional macroseismic scales in a modern context, standardize internet-based collection strategies, and assure compatibility of these alternative approaches of macroseismic data collection.

Even with current best practices, we have identified several limitations with modern macroseismic data collection approaches, particularly from the U.S. Geological Survey's (USGS) perspective. First, whereas crowd-sourced, internet-based intensities such as “Did You Feel It?” (DYFI) are robust and definitive for lower intensities, they are poorly defined above intensity VII, where damage observations warrant expert knowledge of each building’s structural system.

Second, in the U.S., we employ the Modified Mercalli Intensity (MMI) scale, which is consistent with—yet inferior to—the more recently developed European Macroseismic Scale (EMS-98) (Grünthal, 1998). EMS-98 fundamentally advanced the science of macroseismic intensity assignment by requiring quantitative assessments at each location with a consistent application on statistical ranges of well-defined damage grades to specific building vulnerability classes. Lastly, the U.S. and New Zealand no longer have professionals dedicated to collecting macroseismic field surveys, so we also need a strategy to allow post-earthquake building inspectors and loss assessors to help contribute to intensity assignments.

The goals of our International Macroseismic Scale (IMS) Workshop were thus twofold. First, harmonize the MMI scale with EMS-98 for the U.S. and New Zealand—which share several similar building types—by considering those structures and associated damage grades that are not well represented in EMS-98 building vulnerability class table. Next, begin to formalize the process of augmenting EMS-98 with new regional building classes and damage grades towards the development of an IMS. Such an effort necessarily requires reviewing and expanding the original EMS-98 explanatory documents and considering of any required revisions. Fortunately, we can build on the shoulders of giants in that some of the original EMS-98 developers and experts participated in and were integral to our workshop. Their background and guidance were key in moving forward towards an IMS.

We agreed that additional building vulnerability classes, damage grades, and written and pictorial descriptions are necessary and ideally accompanied by a detailed paper trail for other nations to follow. If we can improve the macroseismic assignment process in both nations, we can also aim to refine the process of collecting post-earthquake impact data, a boon to many engineering and financial concerns.

Eos

A Common Language for Reporting Earthquake Intensities

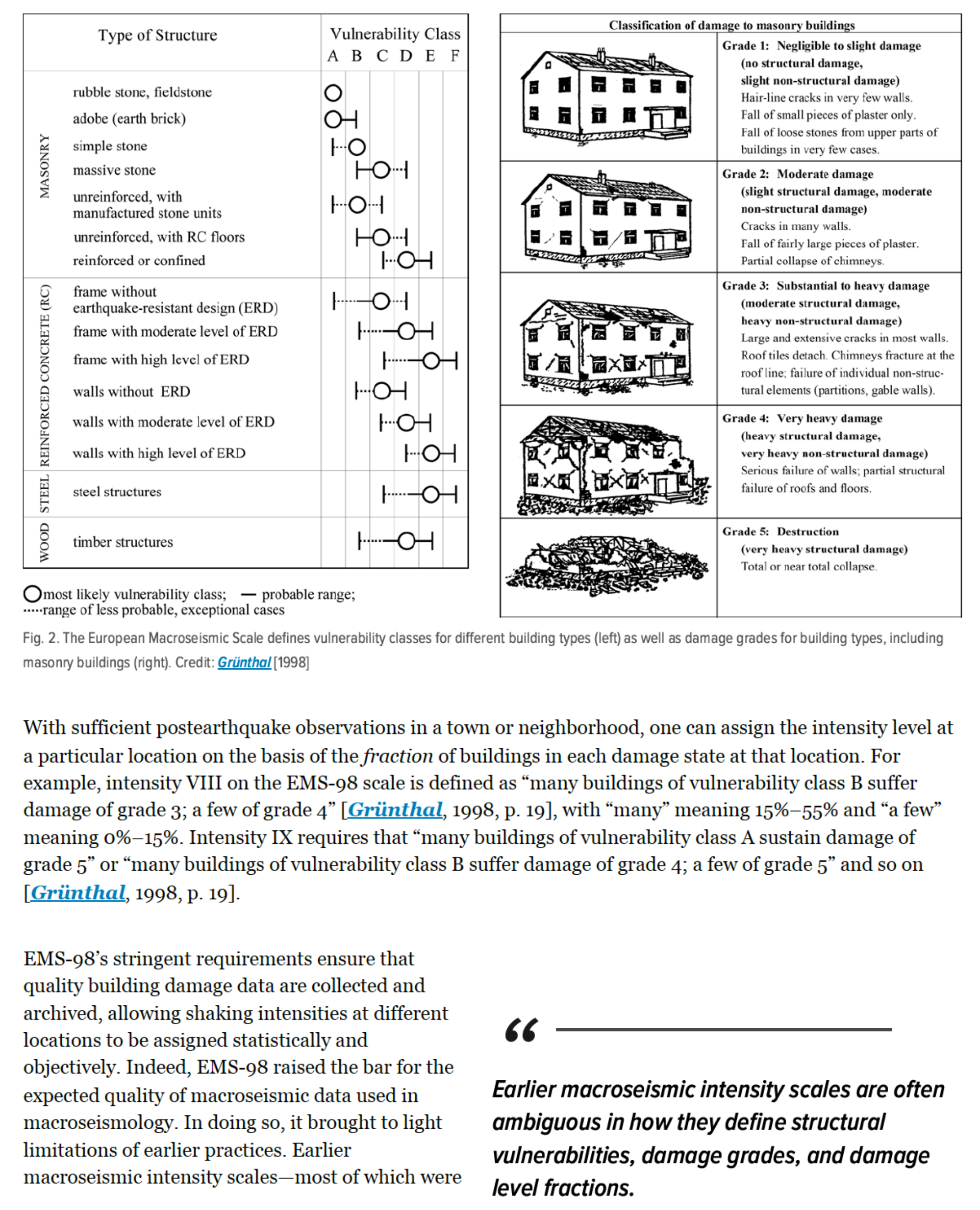
Scientists are working together to establish a standardized international scale for measuring and reporting the intensities and impacts of earthquake shaking.

By **David J. Wald**, **Sabine Loos**, **Robin Spence**, **Tatiana Goded**, and **Ayse Hortacsu**

21 April 2023

Search and rescue efforts continued in Hatay Province in Türkiye, on 12 February amid the damage caused by intense shaking from two earthquakes on 6 February. Credit: Anadolu Agency/Getty Images

Crossing Europe by train used to be far more challenging than it is today. Travelers were required to pass through sometimes complicated and confusing passport checks at each international border and carry cash in various currencies (or—ugh—traveler's checks). The expansion of the European Union (specifically, the **Schengen Area**) and the creation of the **Eurozone** largely resolved these challenges by eliminating barriers to travel across borders and adopting the euro as a common currency among many countries.



Grade 1: Negligible to slight damage
(no structural damage, slight non-structural damage)
Hair-line cracks in very few walls.
Fall of small pieces of plaster only.
Fall of loose stones from upper parts of buildings in very few cases.

Grade 2: Moderate damage
(slight structural damage, moderate non-structural damage)
Cracks in many walls.
Fall of fairly large pieces of plaster.
Partial collapse of chimneys.

Grade 3: Substantial to heavy damage
(moderate structural damage, heavy non-structural damage)
Large and extensive cracks in most walls.
Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).

Grade 4: Very heavy damage
(heavy structural damage, very heavy non-structural damage)
Serious failure of walls; partial structural failure of roofs and floors.

Grade 5: Destruction
(very heavy structural damage)
Total or near total collapse.

Fig. 2. The European Macroseismic Scale defines vulnerability classes for different building types (left) as well as damage grades for building types, including masonry buildings (right). Credit: ***Grünthal*** [1998]

With sufficient postearthquake observations in a town or neighborhood, one can assign the intensity level at a particular location on the basis of the *fraction* of buildings in each damage state at that location. For example, intensity VIII on the EMS-98 scale is defined as "many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4" [***Grünthal***, 1998, p. 19], with "many" meaning 15%–55% and "a few" meaning 0%–15%. Intensity IX requires that "many buildings of vulnerability class A sustain damage of grade 5" or "many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5" and so on [***Grünthal***, 1998, p. 19].

EMS-98's stringent requirements ensure that quality building damage data are collected and archived, allowing shaking intensities at different locations to be assigned statistically and objectively. Indeed, EMS-98 raised the bar for the expected quality of macroseismic data used in macroseismology. In doing so, it brought to light limitations of earlier practices. Earlier macroseismic intensity scales—most of which were

> **“**
>
> ***Earlier macroseismic intensity scales are often ambiguous in how they define structural vulnerabilities, damage grades, and damage level fractions.***

nzsee
NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING

2023

International alignment and update of the New Zealand earthquake intensity scale

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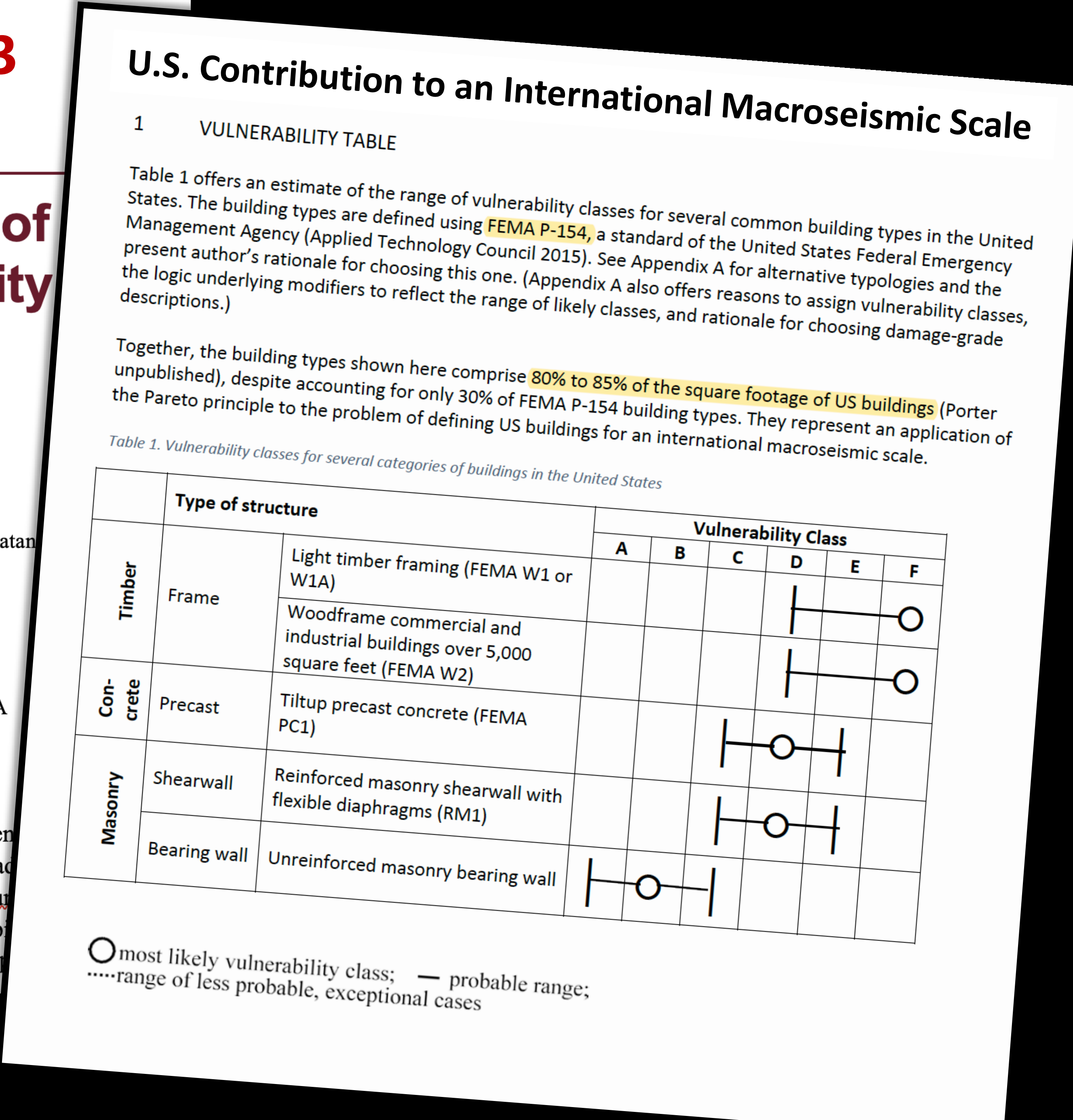
ABSTRACT

The New Zealand Modified Mercalli intensity (MMI) scale was last revised in 2008. Even
scale's lack of specificity on New Zealand's structures for MMI>8 intensity levels has mad
difficult to assign values for recent large earthquakes such as in Christchurch and Kaikōur
paper outlines the progress of New Zealand engineers and seismologists towards develop
intensity scale to be aligned with an International Macroseismic Scale, also under develop



U.S. Contribution to an International Macroseismic Scale

1 VULNERABILITY TABLE

Table 1 offers an estimate of the range of vulnerability classes for several common building types in the United States. The building types are defined using FEMA P-154, a standard of the United States Federal Emergency Management Agency (Applied Technology Council 2015). See Appendix A for alternative typologies and the present author's rationale for choosing this one. (Appendix A also offers reasons to assign vulnerability classes, the logic underlying modifiers to reflect the range of likely classes, and rationale for choosing damage-grade descriptions.)

Together, the building types shown here comprise 80% to 85% of the square footage of US buildings (Porter unpublished), despite accounting for only 30% of FEMA P-154 building types. They represent an application of the Pareto principle to the problem of defining US buildings for an international macroseismic scale.

Table 1. Vulnerability classes for several categories of buildings in the United States

	Type of structure		Vulnerability Class					
			A	B	C	D	E	F
Timber	Frame	Light timber framing (FEMA W1 or W1A)				├	─	○
		Woodframe commercial and industrial buildings over 5,000 square feet (FEMA W2)				├	─	○
Con-crete	Precast	Tiltup precast concrete (FEMA PC1)			├	○	┤	
Masonry	Shearwall	Reinforced masonry shearwall with flexible diaphragms (RM1)			├	○	┤	
	Bearing wall	Unreinforced masonry bearing wall	├	○	┤			

○ most likely vulnerability class; — probable range;
·····range of less probable, exceptional cases

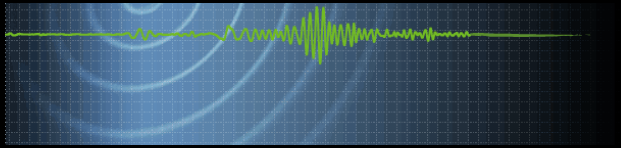
USGS

Combining Lower/higher intensities

- Lower intensities (<=VII) are easily automatically recovered by internet-based acquisition. These make up **> 95%** of all intensity data DYFI collects.

- Higher intensities (>=VII) need expert assignment:
  - Engineering reconnaissance, field surveys, building damage assessments, insurance or aid claims.
  - Remotely via media reports, photos, imagery, social media

- Uncertainties for each observation allows ShakeMap to use DYFI intensities up to VII; Engineering-based assignments would get full weighting where & when they are provided.



USGS has funded Applied Technology Councils’ (ATC) “**ATC-158**”

Specific tasks aimed at a US/NZ regionalization of EMS-98/IMS include the following:

- Evaluate proposed new vulnerability classes for US/NZ buildings,
- Provide damage grade images for each building vulnerability class,
- Evaluate new vulnerability classes & damage descriptors against recent earthquakes

- Help codify macroseismic data collection via various post-earthquake reconnaissance efforts (GEER/ StEER, FEMA, ATC, Surveys, Building Safety Placards, Insurance claims, etc.)

ATC Applied Technology Council

A Nonprofit Corporation
Advancing Engineering Applications for Hazard Mitigation

California, Virginia

ATC 20

PROCEDURES FOR POSTEARTHQUAKE SAFETY EVALUATION OF BUILDINGS

ATC
APPLIED TECHNOLOGY COUNCIL

Funded by
Office of Emergency Services, State of Califo
Office of Statewide Health Planning and Deve
State of California
Federal Emergency Management Agency

ATC-20 Set Report Covers

Addendum to the ATC-20 postearthquake building safety evaluation procedu

ATC Applied Technology Council

Prepared for
National Science Foundation

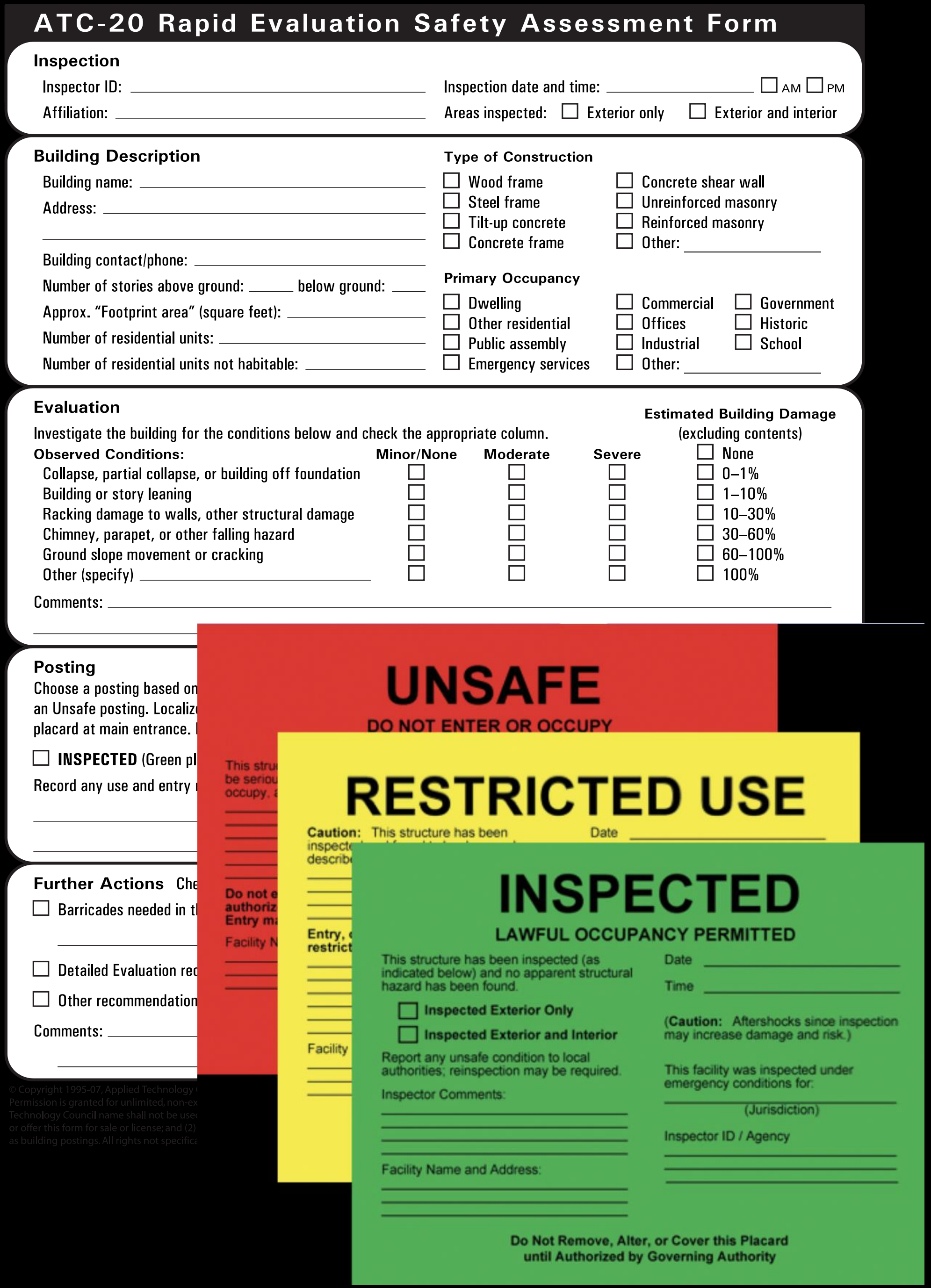
Funded by
U.S. Geological Survey

ATC 20-1

Field manual: postearthquake safety evaluation of buildings

Second Edition

Applied Technology Council



ATC-20 Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: ____________ Inspection date and time: ________ ☐ AM ☐ PM
Affiliation: ____________ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building name: ____________
Address: ____________
____
Building contact/phone: ____________
Number of stories above ground: ______ below ground: ______
Approx. "Footprint area" (square feet): ____________
Number of residential units: ____________
Number of residential units not habitable: ____________

Type of Construction

- ☐ Wood frame
- ☐ Steel frame
- ☐ Tilt-up concrete
- ☐ Concrete frame
- ☐ Concrete shear wall
- ☐ Unreinforced masonry
- ☐ Reinforced masonry
- ☐ Other: ____________

Primary Occupancy

- ☐ Dwelling
- ☐ Other residential
- ☐ Public assembly
- ☐ Emergency services
- ☐ Commercial
- ☐ Offices
- ☐ Industrial
- ☐ Other: ____________
- ☐ Government
- ☐ Historic
- ☐ School

Evaluation

Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe	Estimated Building Damage (excluding contents)
				☐ None
Collapse, partial collapse, or building off foundation	☐	☐	☐	☐ 0–1%
Building or story leaning	☐	☐	☐	☐ 1–10%
Racking damage to walls, other structural damage	☐	☐	☐	☐ 10–30%
Chimney, parapet, or other falling hazard	☐	☐	☐	☐ 30–60%
Ground slope movement or cracking	☐	☐	☐	☐ 60–100%
Other (specify) ____________	☐	☐	☐	☐ 100%

Comments: ____________

Posting

Choose a posting based on
an Unsafe posting. Localiz
placard at main entrance.

☐ **INSPECTED** (Green pl

Record any use and entry

Further Actions Che

☐ Barricades needed in t

☐ Detailed Evaluation re

☐ Other recommendation

Comments: ____________

UNSAFE

DO NOT ENTER OR OCCUPY

This stru
be seriou
occupy, a

Do not e
authoriz
Entry ma

Facility N

RESTRICTED USE

Caution: This structure has been
inspecte
describ

Date ____________

Entry,
restrict

Facility

INSPECTED

LAWFUL OCCUPANCY PERMITTED

This structure has been inspected (as indicated below) and no apparent structural hazard has been found.

☐ **Inspected Exterior Only**

☐ **Inspected Exterior and Interior**

Report any unsafe condition to local authorities; reinspection may be required.

Inspector Comments:

Facility Name and Address:

Date ____________

Time ____________

(**Caution:** Aftershocks since inspection may increase damage and risk.)

This facility was inspected under emergency conditions for:

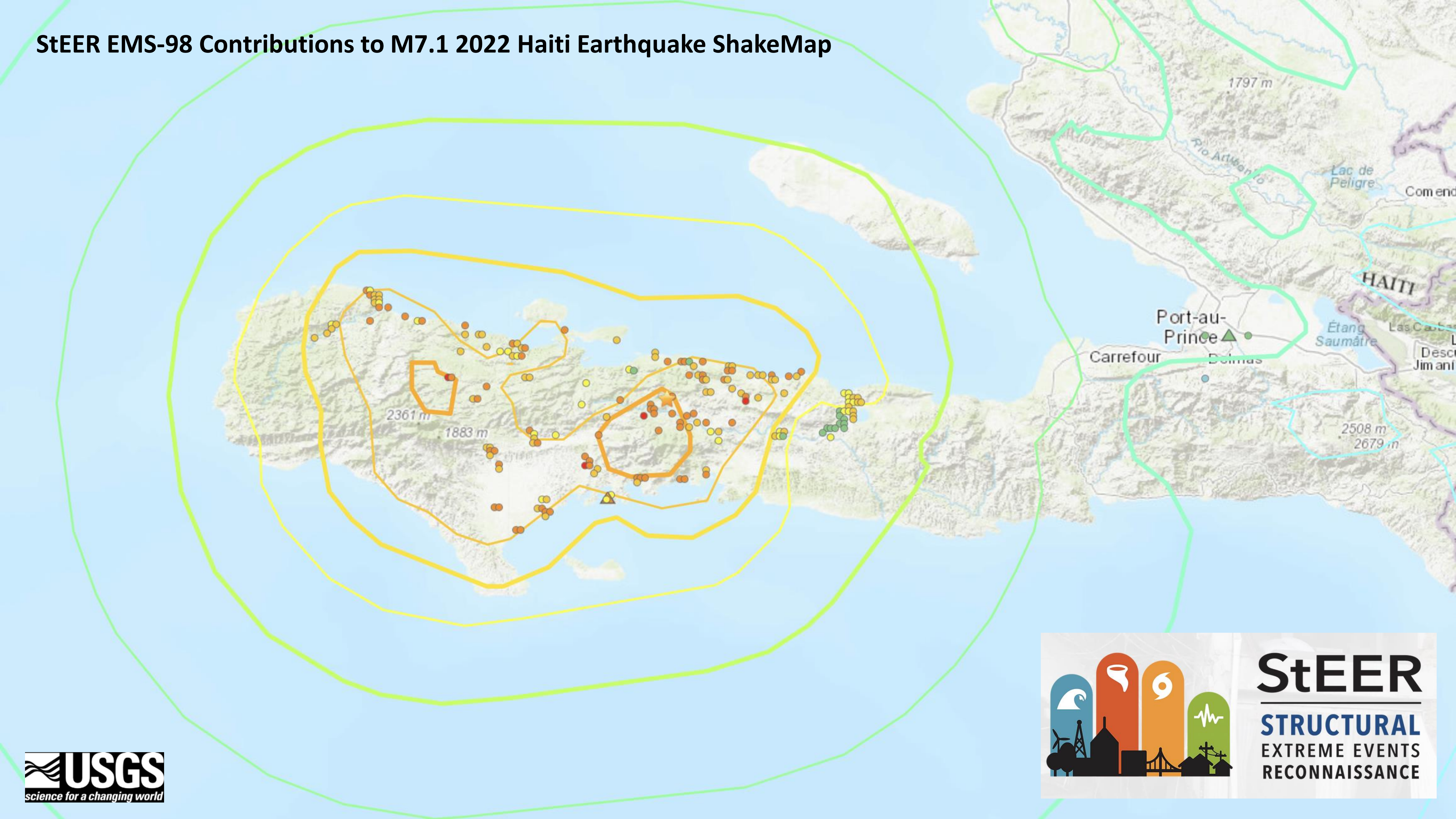
____
(Jurisdiction)

Inspector ID / Agency

Do Not Remove, Alter, or Cover this Placard until Authorized by Governing Authority

USGS

StEER EMS-98 Contributions to M7.1 2022 Haiti Earthquake ShakeMap



USGS
science for a changing world

StEER
STRUCTURAL
EXTREME EVENTS
RECONNAISSANCE

So, What are GEM’s possible roles in IMS Implementation?

- Vitor, Helen, & many others have long appreciated importance of macroseismic intensity.
- GEM originally had a “Macroseismic Working Group”, part of the earlier research collaboration funding model. The value of that effort was not questioned, funding was just limited.
- GEM is uniquely situated as an international entity to help develop, endorse, & help implement IMS in many countries where you are working with contacts & grass roots organizations.
- GEM will benefit from IMS in many of its hazards & risks efforts, particularly from the uniformity & quality of macroseismic & post-earthquake loss data worldwide.

Expression of Interest Macroseismic Intensity

GEM is considering funding activities related to macroseismic intensity and is thus calling for Expressions of Interest (EOI) on the following tasks:

1. Develop a working/archival macroseismic database (at least, metric, e.g., EMS-98, MCS, MMI, DYFI?, etc.; uncertainty rating, location, & reference)*.
2. Coordinate with GEM GMPE & other global hazard & risk components to insure compatible ground motion & intensity strategies/solutions. Ensure compatibility of macroseismic database with GMPE strong-motion database & provide tools to select user-defined spatial intersections of the Ground Motion & Intensity databases.
3. Work with the ESC Internet Macroseismic Working Group to develop XML standards for macroseismic data exchange for historical & Internet-based data sources. Insure future data can be directly incorporated into GEM macroseismic DB.
4. Develop Ground-Motion-to-Intensity conversion equations (GMICE), preferably reversible ones (IGMCE), including uncertainty estimates.
5. Develop direct Intensity Prediction Equations (IPEs) for stable continental interiors & subduction zones (SCR/SZ). Selection of and refinements to existing active crustal region (ACR) IPEs.
6. Develop tools to allow for non-parametric MI attenuation treatment in probabilistic hazard and risk analyses, through direct exploitation of existing/projected intensity databases.
7. Improve/Develop GMPEs for instrumental intensity by utilizing the correlation among peak motions & JMA intensity with MMI, EMS-98, & others.
8. Develop site-terms for IPEs (native to specific relations), & alternatively, corrective amplification terms that might be applied to existing relations.
9. Examine IPE & Conversion Equation transportability/regionalization & recommend use.
10. Develop strategies for testing & evaluation; e.g., select & utilize intensity/ground motion pairs at sites for specific ShakeMap events for selected GMPE/IPE/ GMICE/IGMCE combinations for Testing & Evaluation.
11. Refine & provide a Global GMPE/IPE/GMICE Selector Tool. Based on results of tasks 8 & 9.
12. Coordinate development of a GMS (Global Macroseismic Scale), as an extension of the European Macroseismic Scale. This would be an international, multi-year effort.

*A comprehensive archival database is likely beyond the scope of this task. However, a subtask could be to scope existing data/databases & the level of effort that would be needed to develop a true archive: Options: a) macroseismic observations co-located with strong motion instruments (for developing conversion relations) and, b) data required for the development of systematic, regional/global intensity prediction equations. Option a) is a much smaller subset of macroseismic data than option b).

If you would like to submit an Expression of Interest, please send an email to secretariat@globalquakemodel.org before **May 15th 2011**, with a brief CV (either of yourself or your organisation), and answers to the following questions:

- Which of the proposed macroseismic activities would you or your organisation be interested in undertaking? Are there any additional or alternative tasks that you feel GEM should tackle? Do you believe any of the aforementioned tasks are not needed?
- What relevant qualifications or experience related to these activities do you or your organisation have?
- Would you be in a position to provide any of the proposed activities as an inkind contribution to GEM?

Ongoing USGS Macroseismic R&D

- Macroseismic Database (IMDB): SGM & Macroseismic data in ShakeMap Atlas

- Ground Motion Intensity Conversion Equation (GMICE) enhancements.

- Intensity Prediction Equation (IPEs) improvements/development

- Uncertainty quantification via residual analyses:

    - DYFI
    - Historical (archival & revisited)
    - Modern field-based
    - Modern, but remote, media

- Spatial, spectral cross-correlation with other ground motion intensity measures (IMs)

Take-aways

- As a shaking metric, intensity connects human, seismological & engineering analyses
- Today’s uses of macroseismic intensity data
    - Historical earthquake documentation with macroseismology
    - Ground motion seismology
    - Loss modeling & risk analyses
    - Sociological analyses of human behavior in earthquakes
- Challenges of modern macroseismic practices & intensity data more generally, including legacy MMI scale is outdated. US/NZ moving on to EMS-98-like scale.
- Moving forward: An evolution towards an International Macroseismic Scale (IMS) leveraging reconnaissance & inspection teams to facilitate assignments.
- With collaboration & help from GEM, we can make this happen!

CURRENT IMS Calendar

- GEM Conference (June 13-14, 2023) (This meeting!)

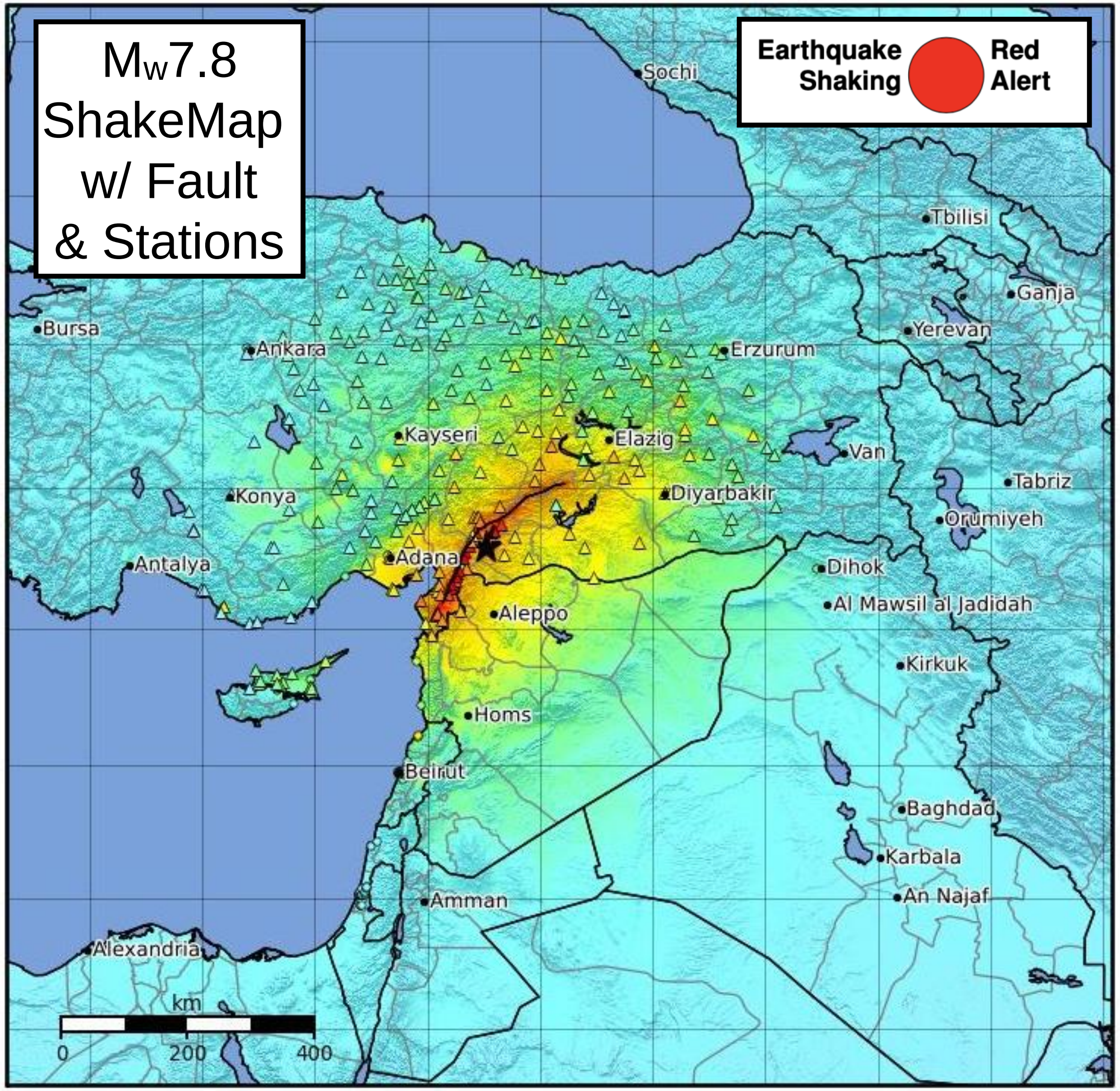
- Potsdam IMS'24 Working Group Workshop (July 13-14, GFZ Potsdam)
  - Grunthal, Musson, Schwarz, Spence Wald, Wenk, [Silva]

- USGS Powell Center Workshop #2 (Fort Collins, Colorado, Oct 2-6, 2023)
  - US/NZ results; assignments via reconnaissance,
  - Planning international adaption/adoption efforts.

- 18th World Conf on Earthquake Engineering (18WCEE). Milan, July 2024.
  - Special Session on IMS & Macroseismology (26 papers!).

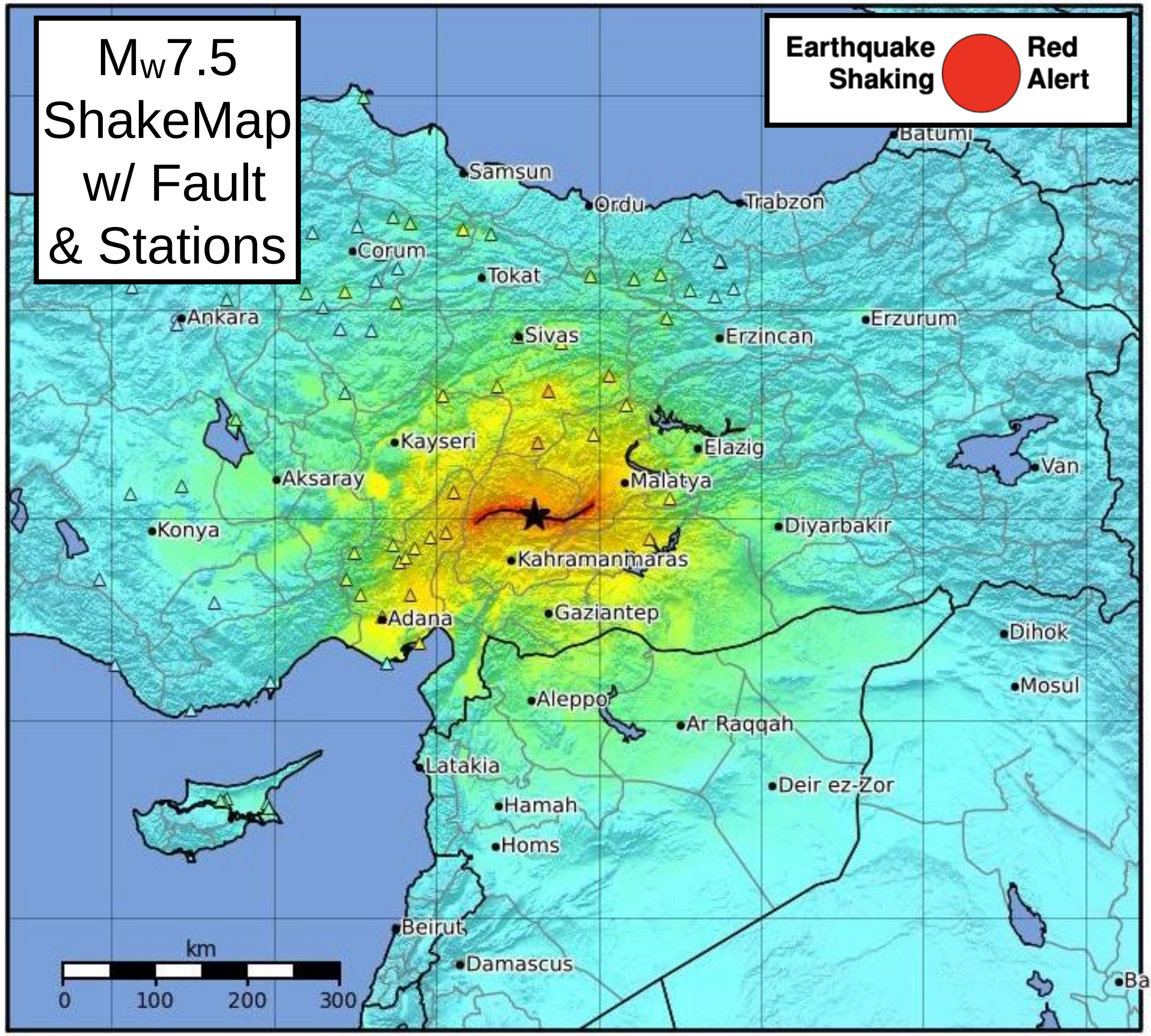
- In the interim: Routine US/NZ meetings on IMS Implementations; R&D

2023 Gaziantep Earthquake Sequence Response Timeline



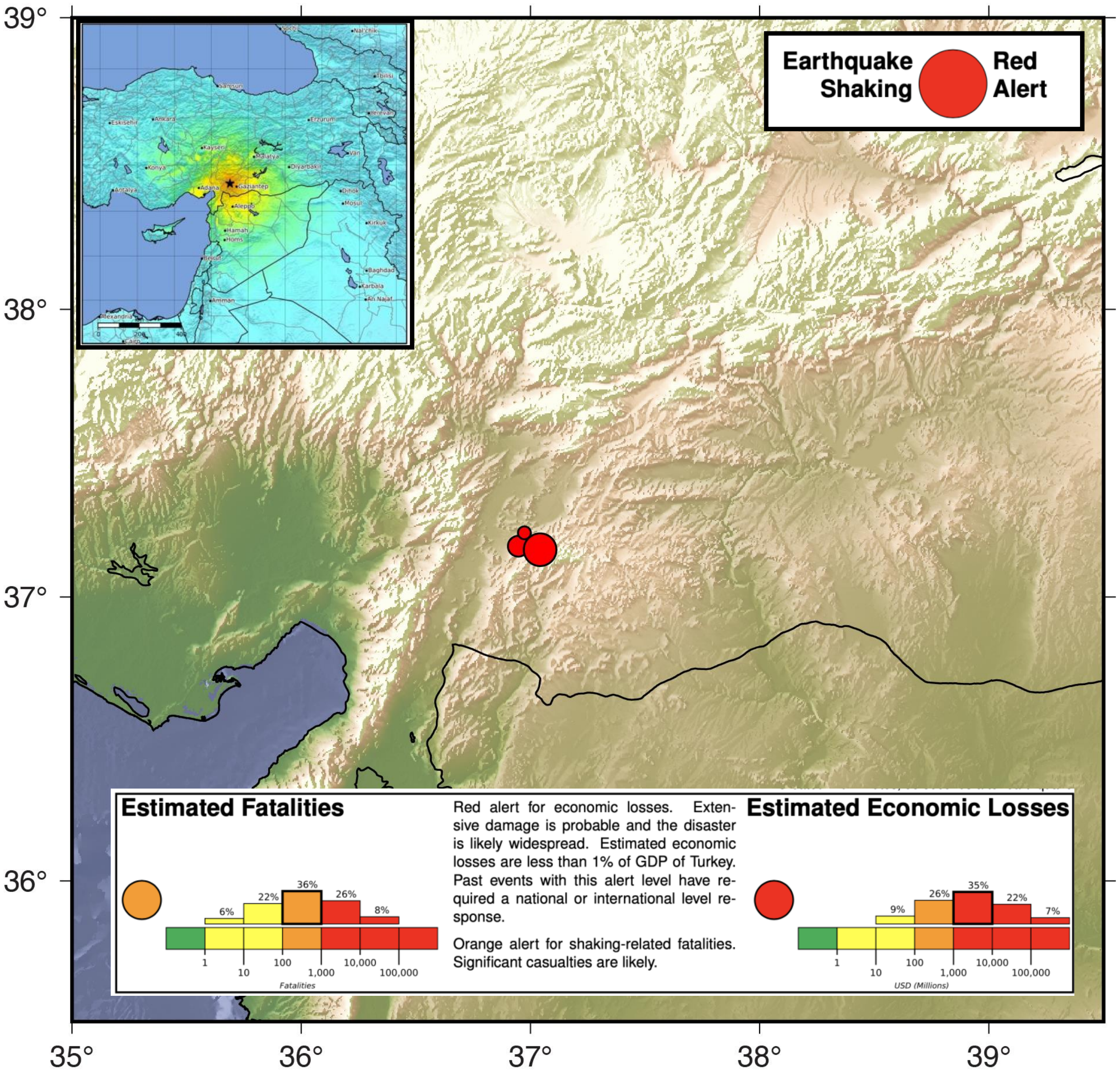
M_W7.8 ShakeMap w/ Fault & Stations

Earthquake Shaking ● Red Alert



M_W7.5 ShakeMap w/ Fault & Stations

Earthquake Shaking ● Red Alert



Red alert for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are less than 1% of GDP of Turkey. Past events with this alert level have required a national or international level response.

Orange alert for shaking-related fatalities. Significant casualties are likely.

2023 Gaziantep Earthquake Sequence Response Timeline

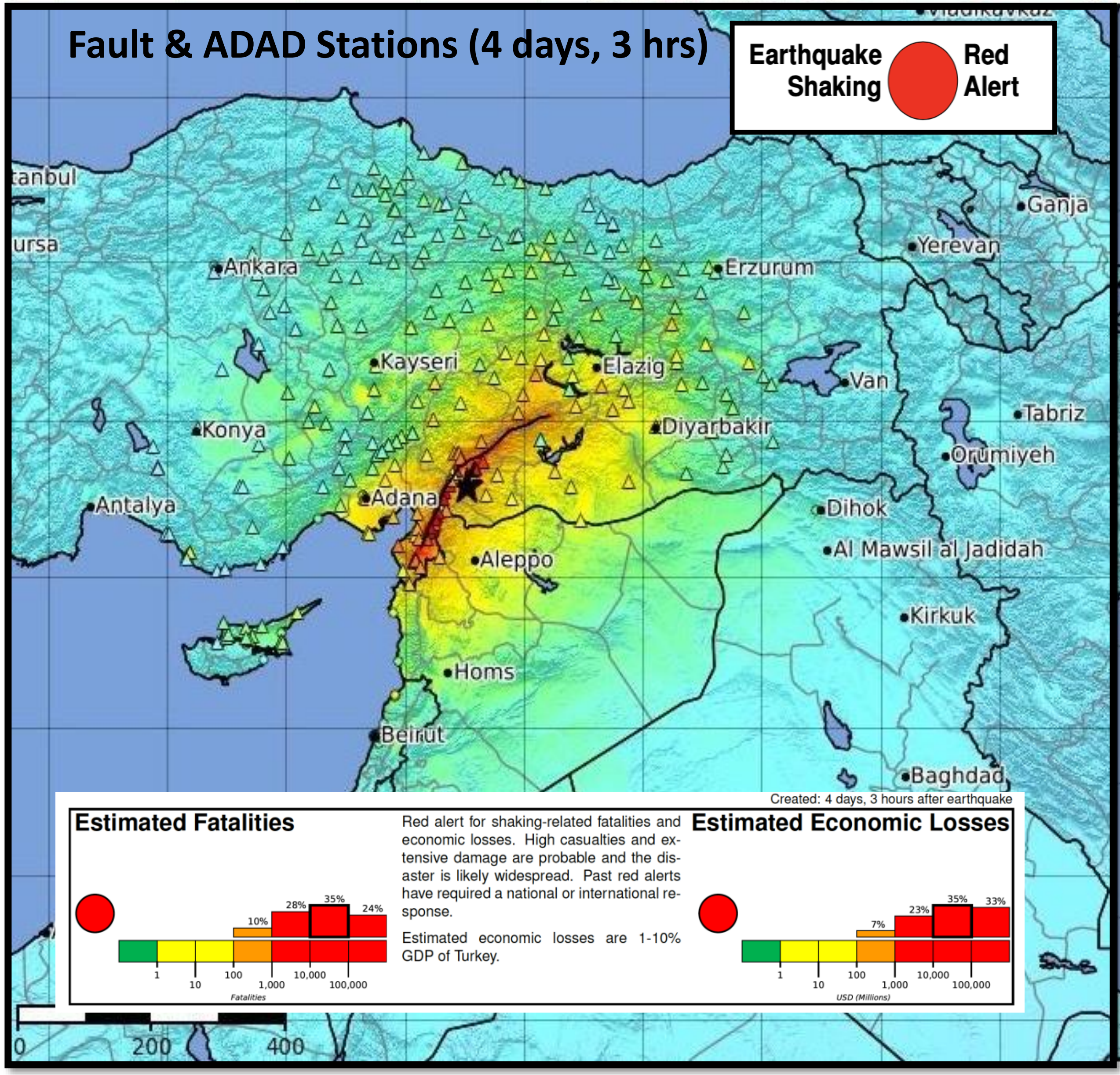
February 6, 2023
M_w7.8: 01:17 UTC
M_w6.7: 01:28 UTC

NEIC Origin Release
OT+ **11.4 min**
M_{ww}7.8

ShakeMap Release
OT + **15.7 min**

PAGER Release
OT + **21.2 min**

Fault & ADAD Stations (4 days, 3 hrs)



Created: 4 days, 3 hours after earthquake

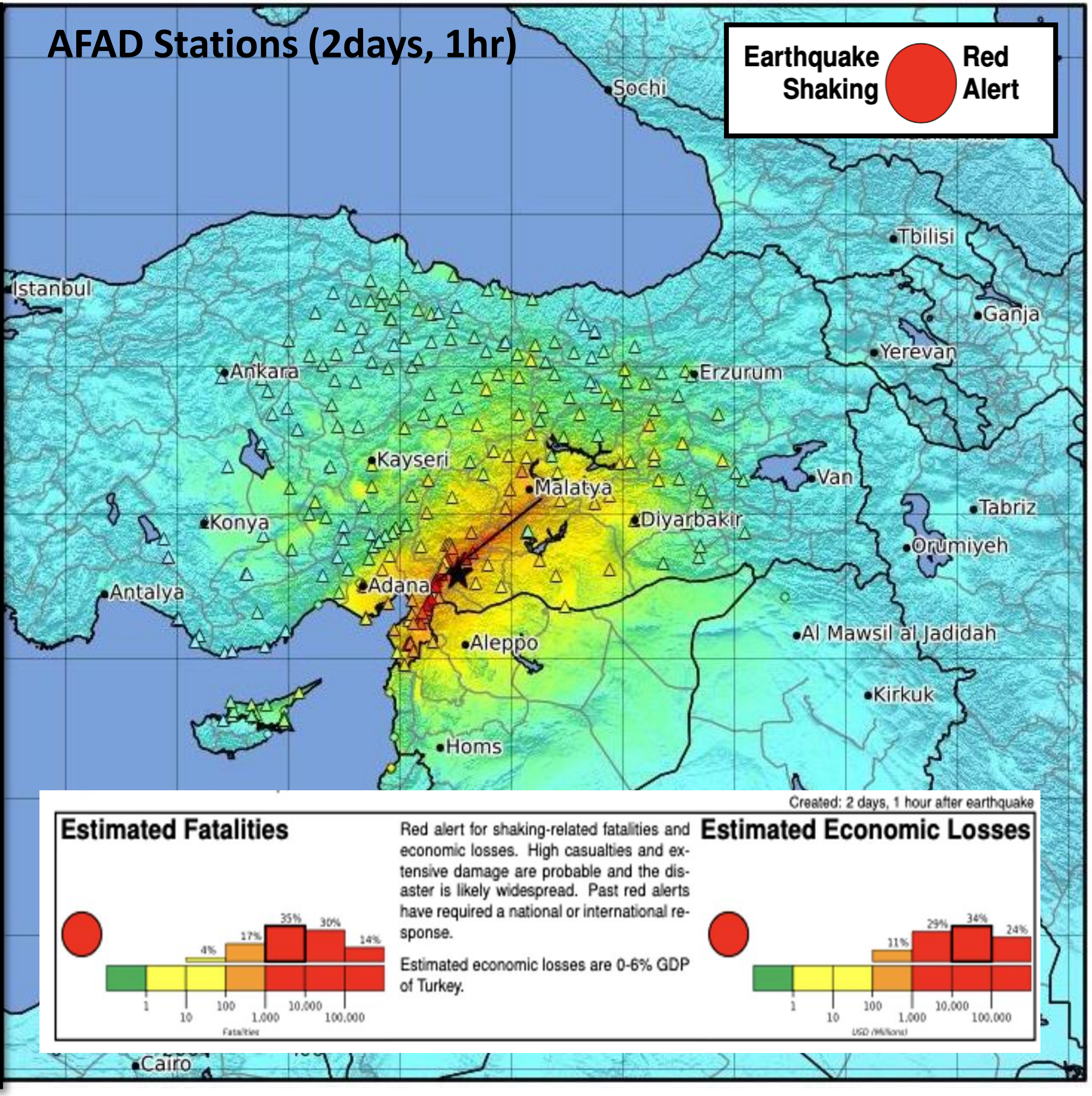
Estimated Fatalities

Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 1-10% GDP of Turkey.

Estimated Economic Losses

AFAD Stations (2days, 1hr)



Created: 2 days, 1 hour after earthquake

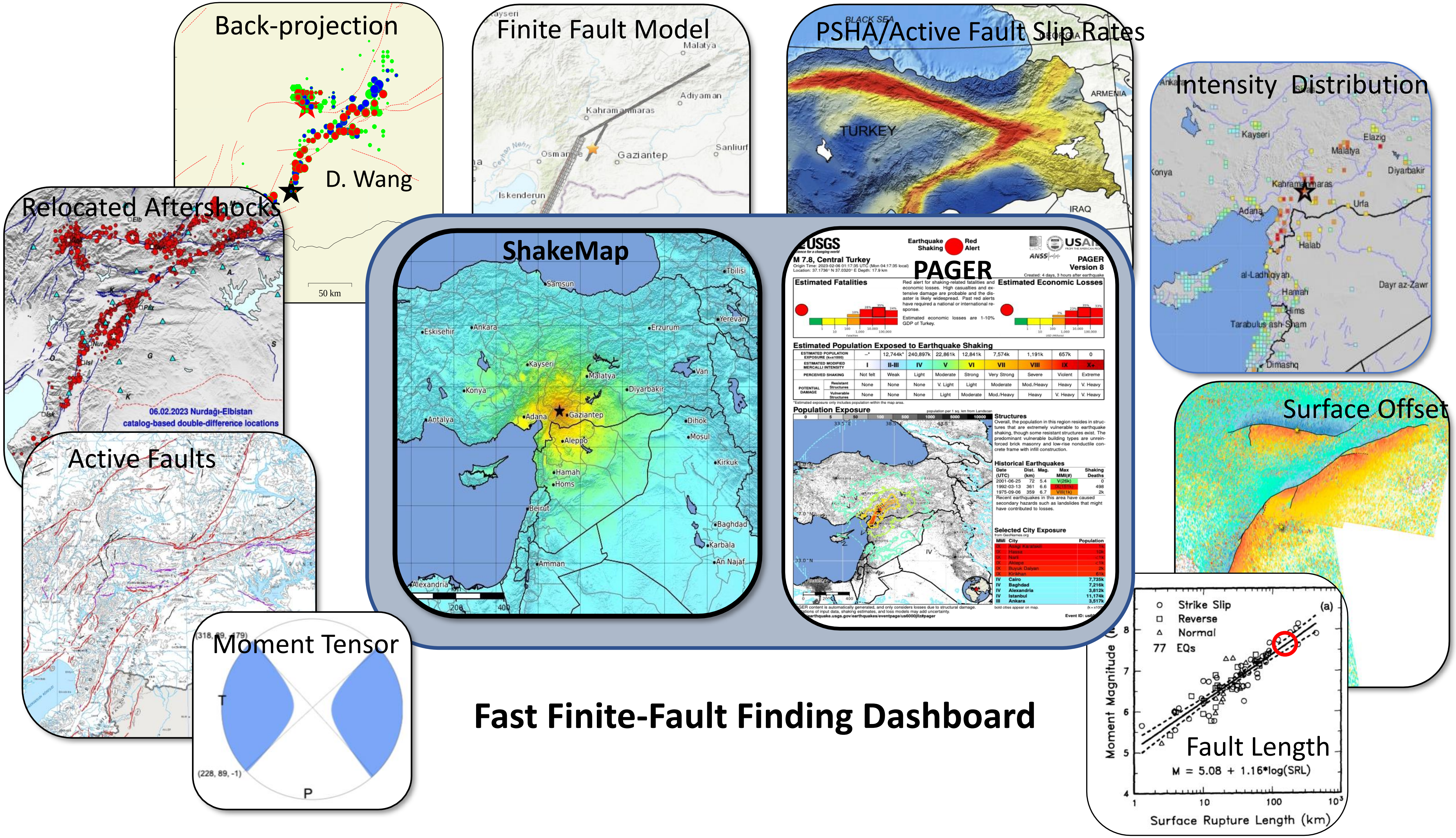
Estimated Fatalities

Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 0-6% GDP of Turkey.

Estimated Economic Losses

Fast Finite-Fault Finding Dashboard



USGS
science for a changing world

Earthquake Shaking ● Red Alert

ANSS
USAID FROM THE AMERICAN PEOPLE

M 7.8, Central Turkey
Origin Time: 2023-02-06 01:17:35 UTC (Mon 04:17:35 local)
Location: 37.1736° N 37.0320° E Depth: 17.9 km

PAGER
Version 8
Created: 4 days, 3 hours after earthquake

Estimated Fatalities

Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 1-10% GDP of Turkey.

Estimated Economic Losses

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k=x1000)		--*	12,744k*	240,897k	22,861k	12,841k	7,574k	1,191k	657k	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

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 unreinforced brick masonry and low-rise nonductile concrete frame with infill construction.

Historical Earthquakes

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
2001-06-25	72	5.4	V(26k)	0
1992-03-13	361	6.6	IX(151k)	498
1975-09-06	359	6.7	VIII(1k)	2k

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

Selected City Exposure
from GeoNames.org

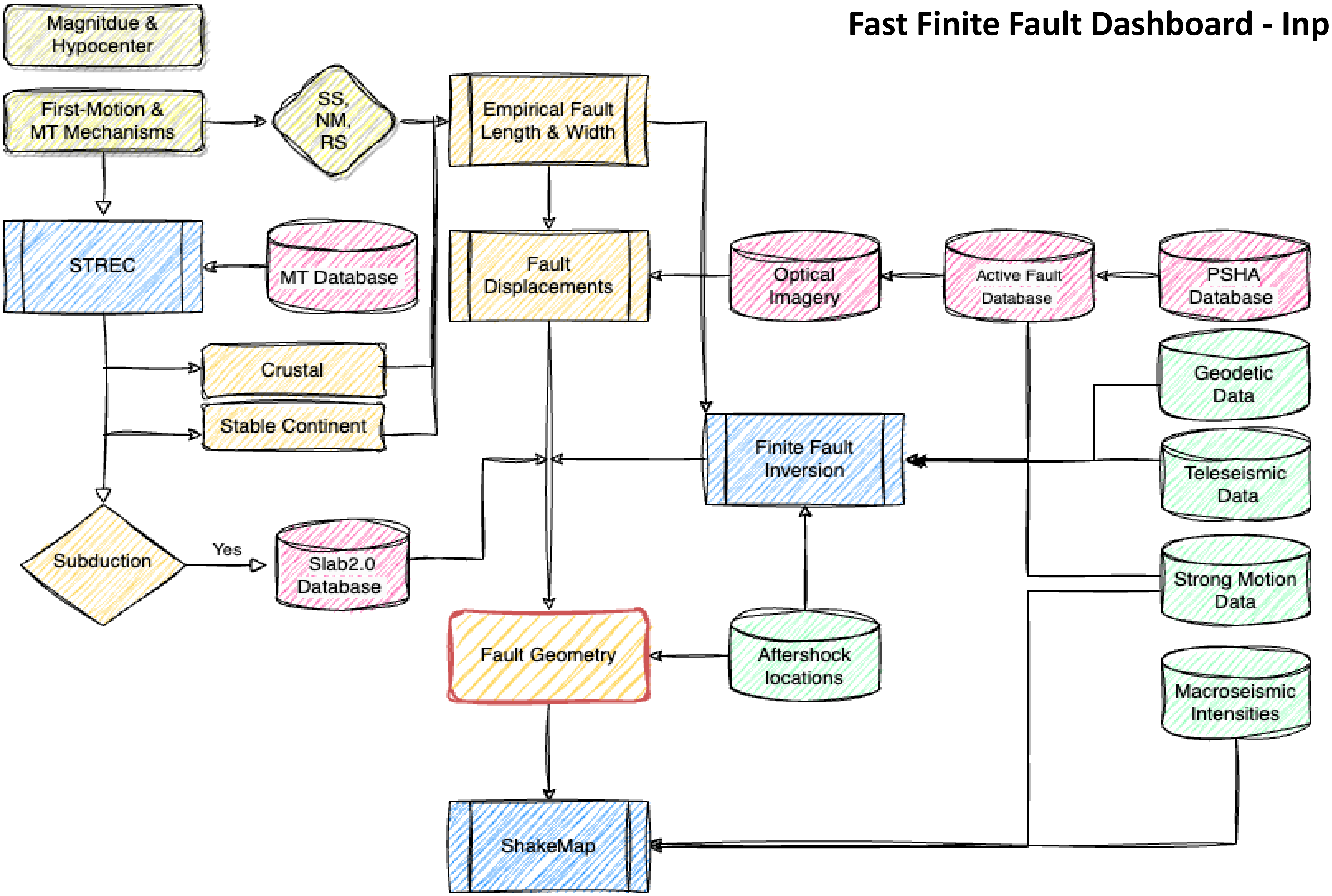
MMI	City	Population
IX	Asagi Karafakili	1k
IX	Hassa	10k
IX	Narli	<1k
IX	Aktepe	<1k
IX	Buyuk Dalyan	2k
IX	Kirikhan	61k
IV	**Cairo**	7,735k
IV	**Baghdad**	7,216k
IV	**Alexandria**	3,812k
IV	**Istanbul**	11,174k
III	**Ankara**	3,517k

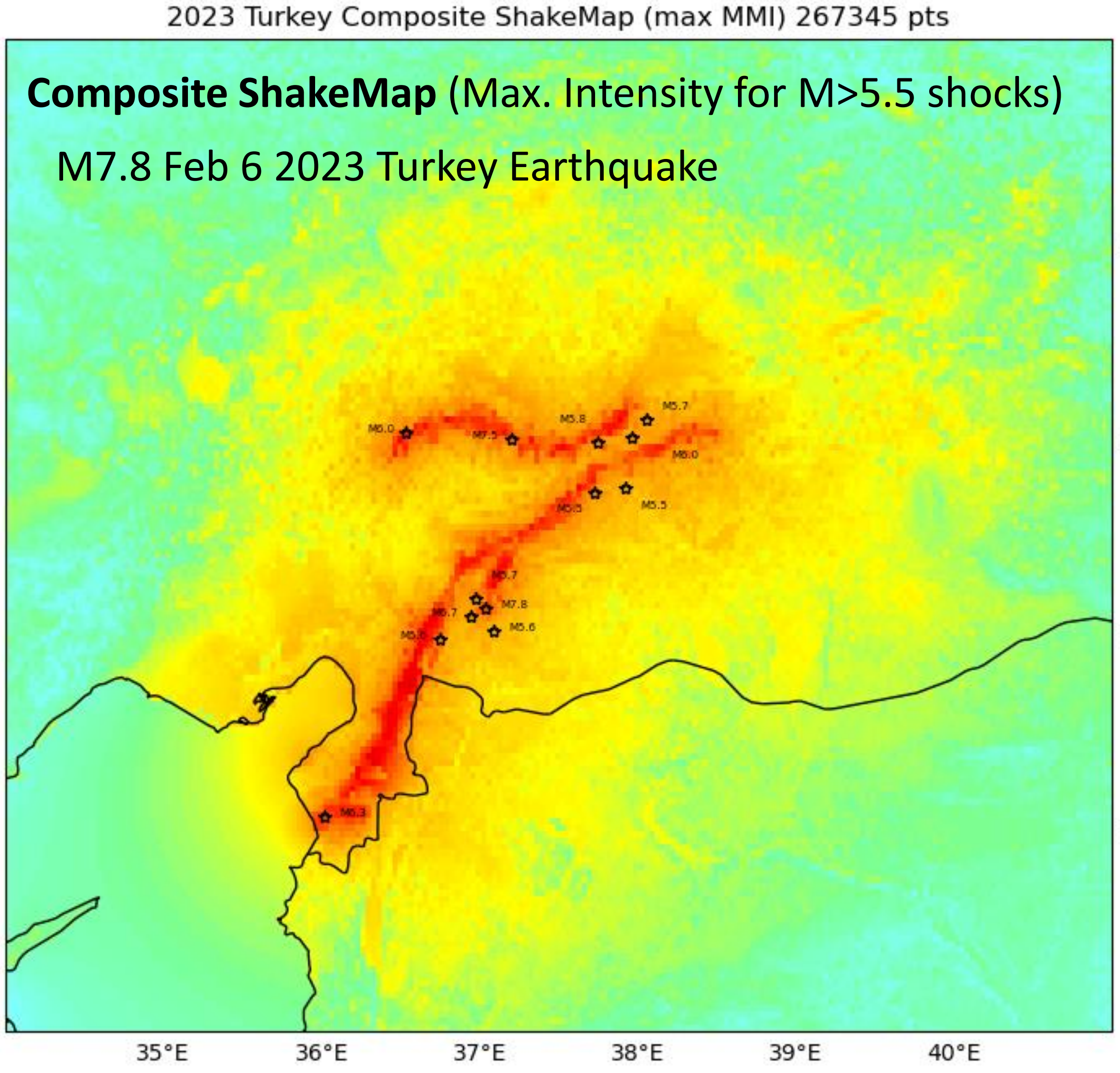
bold cities appear on map. (k = x100

GER content is automatically generated, and only considers losses due to structural damage.
tations of input data, shaking estimates, and loss models may add uncertainty.
earthquake.usgs.gov/earthquakes/eventpage/us6000jllz#pager

Event ID: us6

Fast Finite Fault Dashboard - Inputs





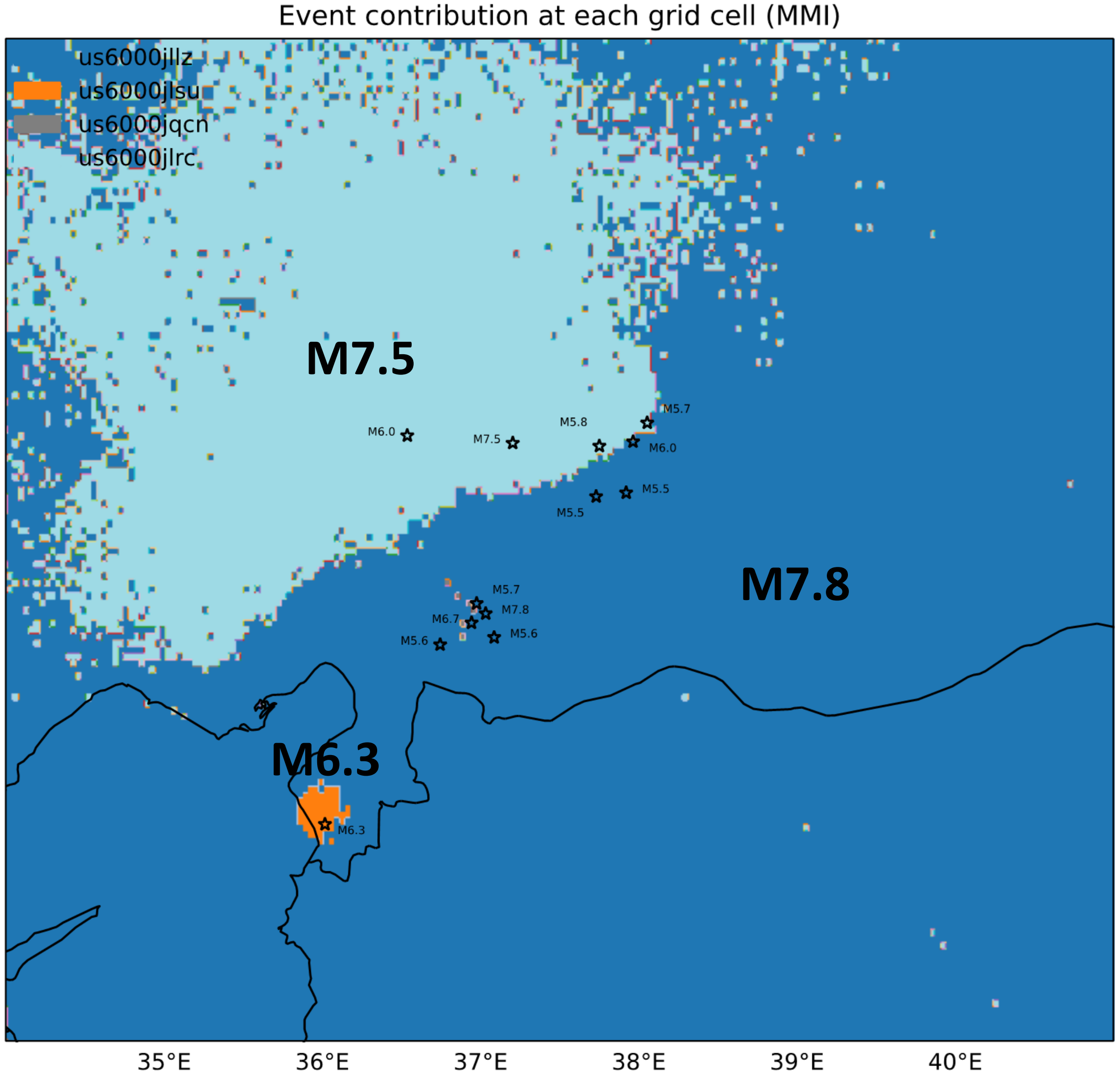
Composite ShakeMap (Max. Intensity for M>5.5 shocks)

M7.8 Feb 6 2023 Turkey Earthquake

SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 1: Processed 2023-02-06T01:29:53Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter



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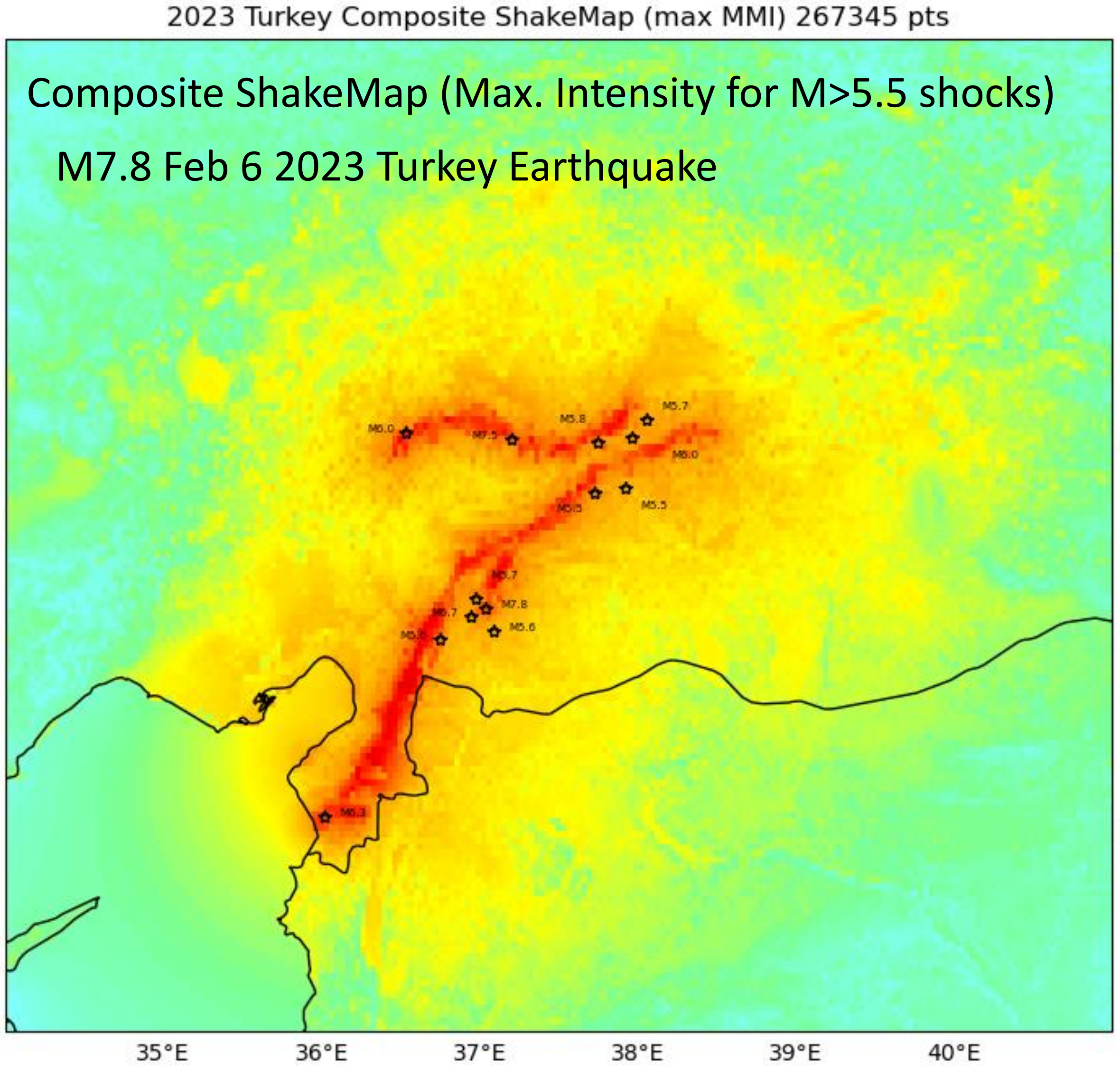

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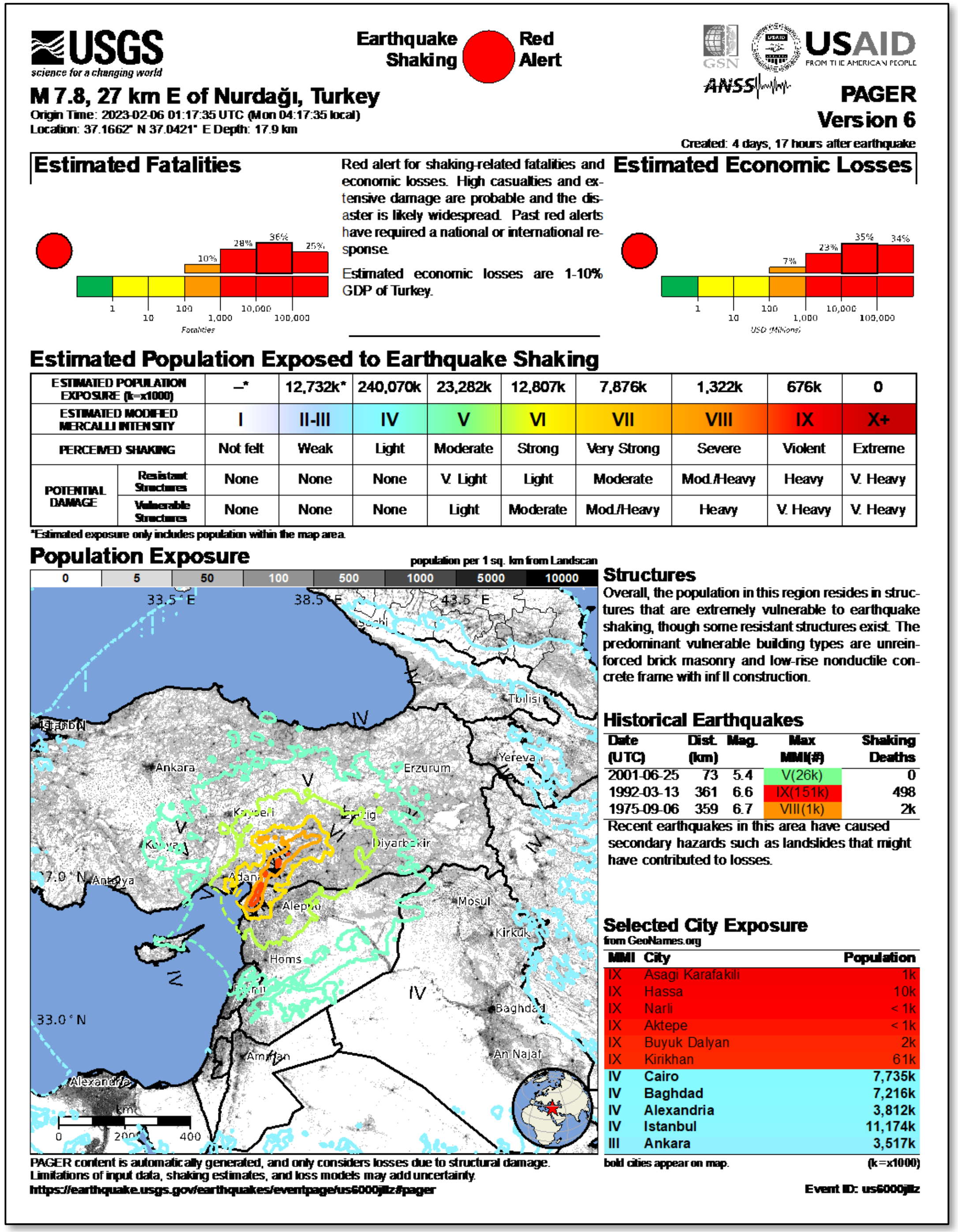

USGS science for a changing world

Earthquake Shaking 🔴 Red Alert

GSN USAID FROM THE AMERICAN PEOPLE ANSS

M 7.8, 27 km E of Nurdağı, Turkey

Origin Time: 2023-02-06 01:17:35 UTC (Mon 04:17:35 local)
Location: 37.1662° N 37.0421° E Depth: 17.9 km

PAGER
Version 6

Created: 4 days, 17 hours after earthquake

Estimated Fatalities

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ESTIMATED POPULATION EXPOSURE (k=x1000)		–*	12,732k*	240,070k	23,282k	12,807k	7,876k	1,322k	676k	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

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/us6000jllz#pager

Structures

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from GeoNames.org

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IX	Aktepe	< 1k
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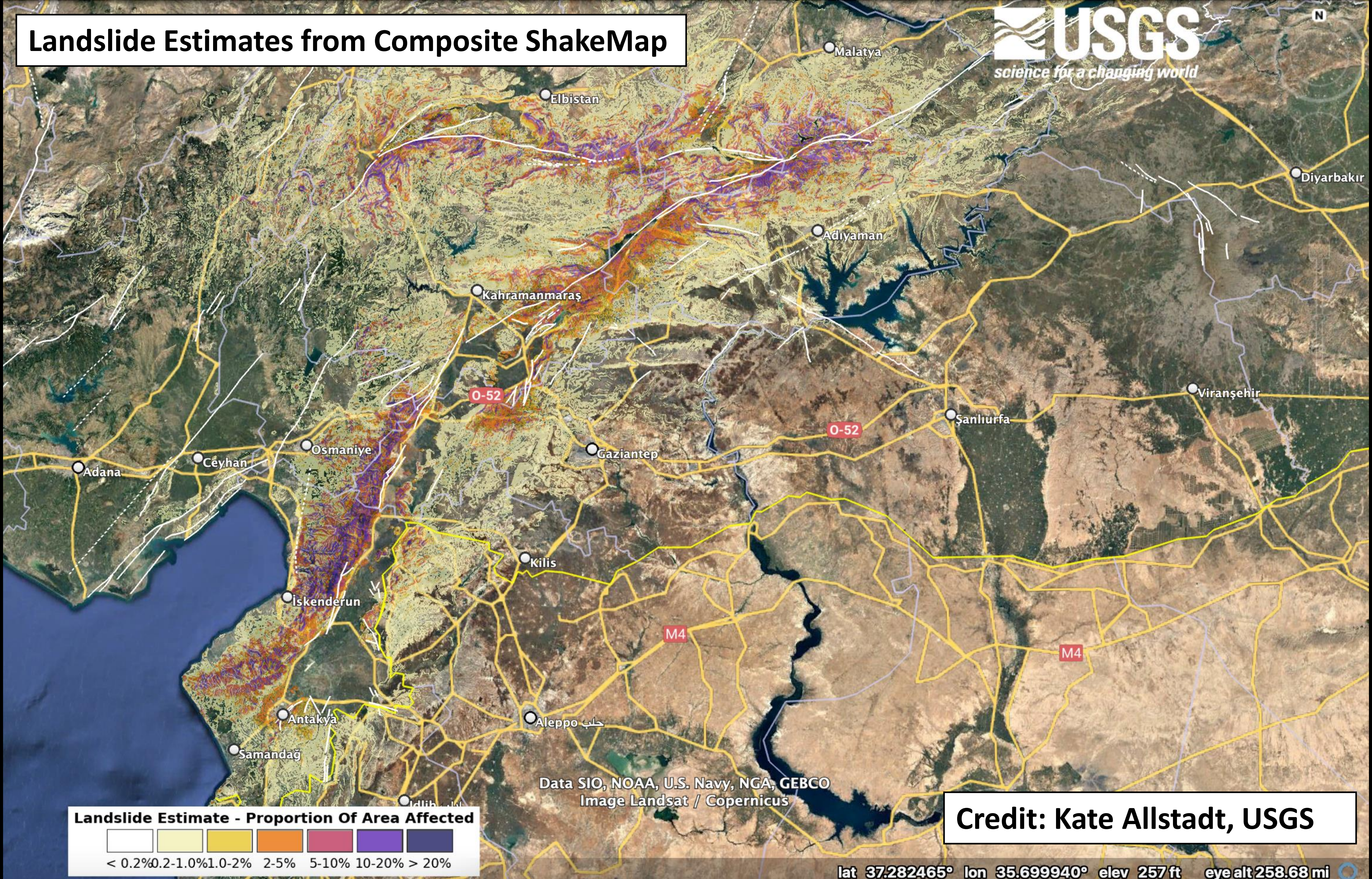
IX	Kirikhan	61k
IV	**Cairo**	7,735k
IV	**Baghdad**	7,216k
IV	**Alexandria**	3,812k
IV	**Istanbul**	11,174k
III	**Ankara**	3,517k

bold cities appear on map. (k=x1000)

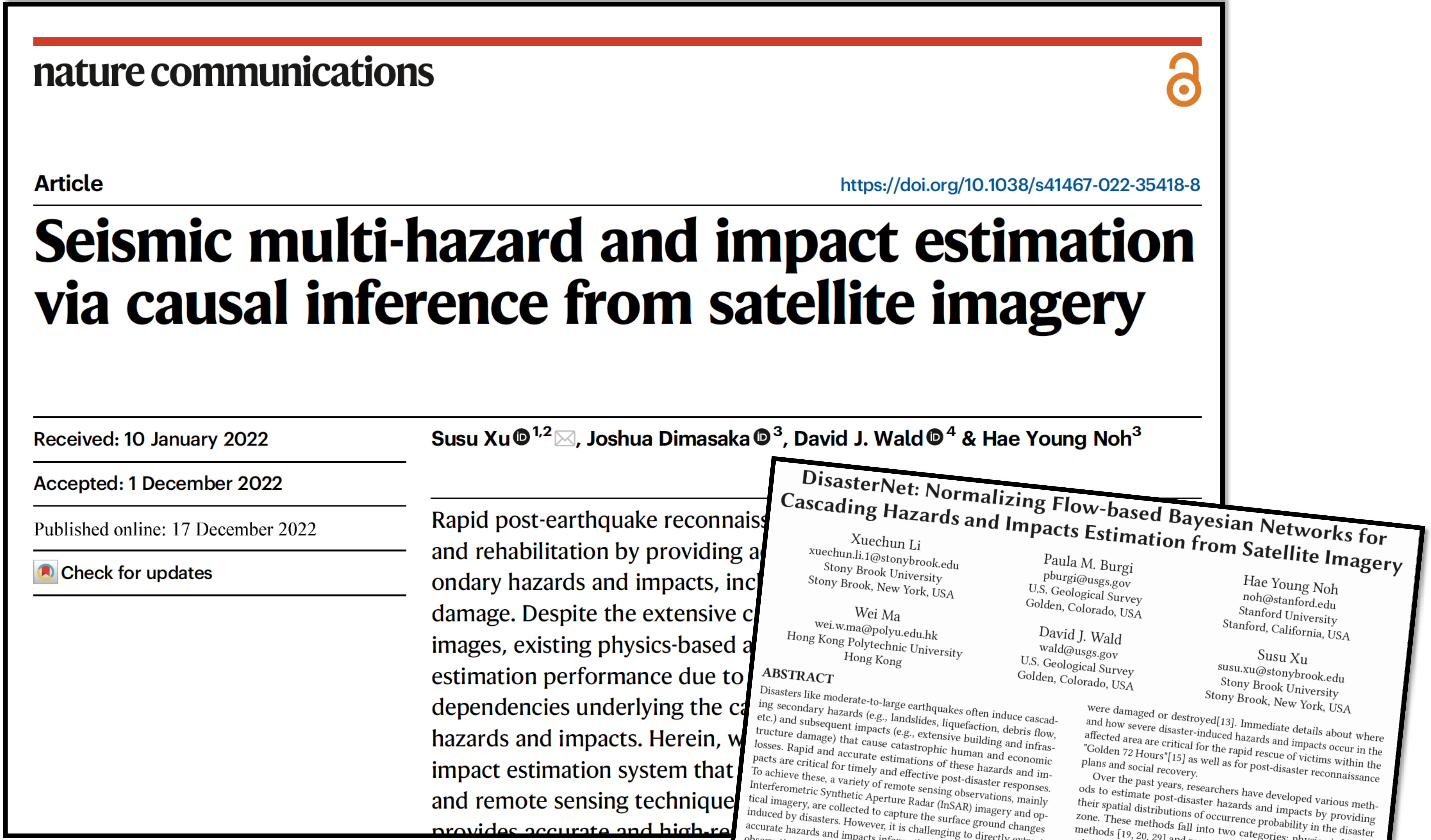
Event ID: us6000jllz

Landslide Estimates from Composite ShakeMap



Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

Credit: Kate Allstadt, USGS



nature communications

Article

https://doi.org/10.1038/s41467-022-35418-8

Seismic multi-hazard and impact estimation via causal inference from satellite imagery

Received: 10 January 2022

Accepted: 1 December 2022

Susu Xu [1,2], Joshua Dimasaka [3], David J. Wald [4] & Hae Young Noh [3]

Rapid post-earthquake reconnaiss
and rehabilitation by providing a
ondary hazards and impacts, inc
damage. Despite the extensive c
images, existing physics-based a
estimation performance due to
dependencies underlying the ca
hazards and impacts. Herein, w
impact estimation system that
and remote sensing technique

DisasterNet: Normalizing Flow-based Bayesian Networks for Cascading Hazards and Impacts Estimation from Satellite Imagery

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ABSTRACT

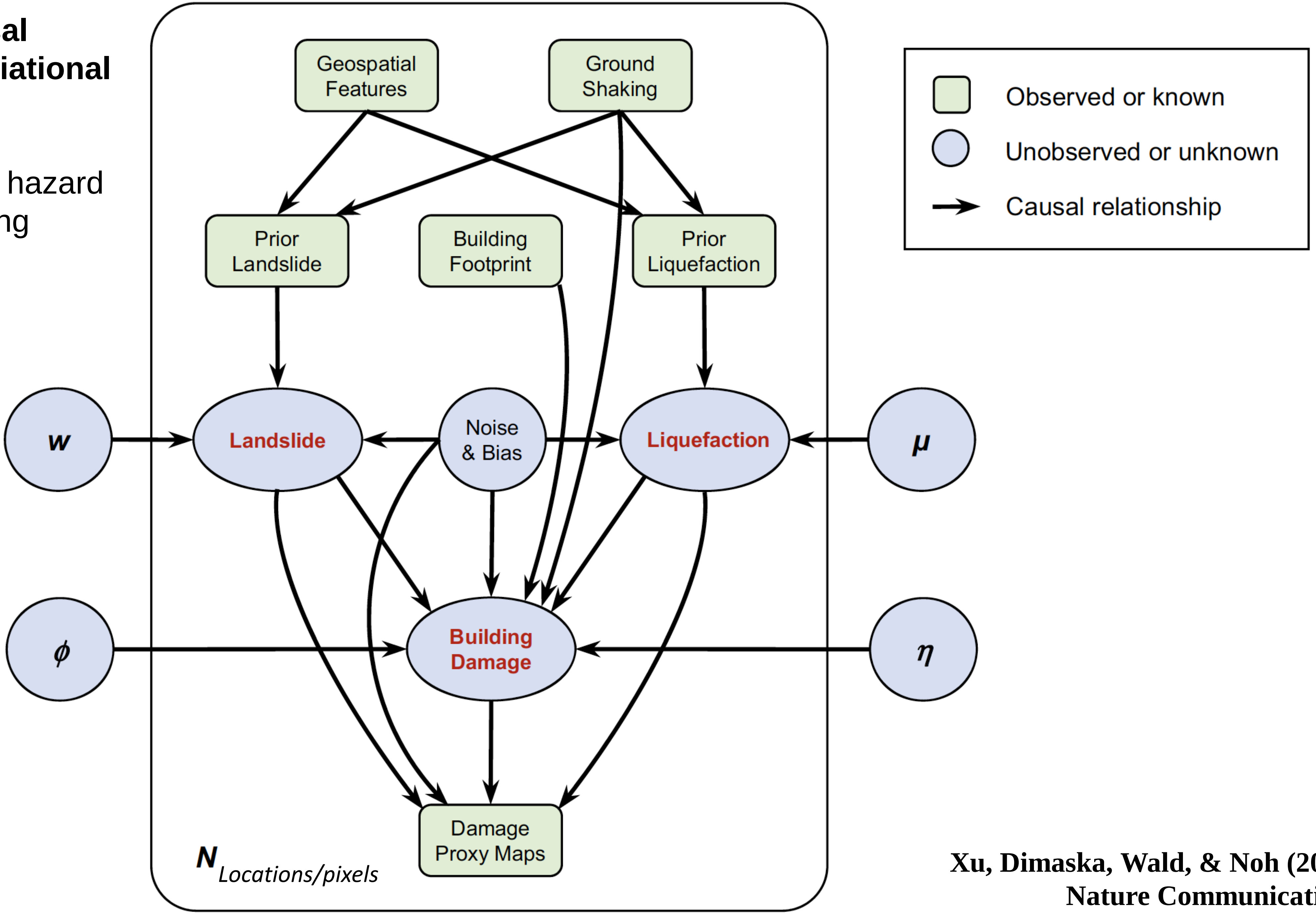
Disasters like moderate-to-large earthquakes often induce cascading secondary hazards (e.g., landslides, liquefaction, debris flow, etc.) and subsequent impacts (e.g., extensive building and infrastructure damage) that cause catastrophic human and economic losses. Rapid and accurate estimations of these hazards and impacts are critical for timely and effective post-disaster responses. To achieve these, a variety of remote sensing observations, mainly Interferometric Synthetic Aperture Radar (InSAR) imagery and optical imagery, are collected to capture the surface ground changes induced by disasters. However, it is challenging to directly extract accurate hazards and impacts

were damaged or destroyed[13]. Immediate details about where and how severe disaster-induced hazards and impacts occur in the affected area are critical for the rapid rescue of victims within the "Golden 72 Hours"[15] as well as for post-disaster reconnaissance plans and social recovery.

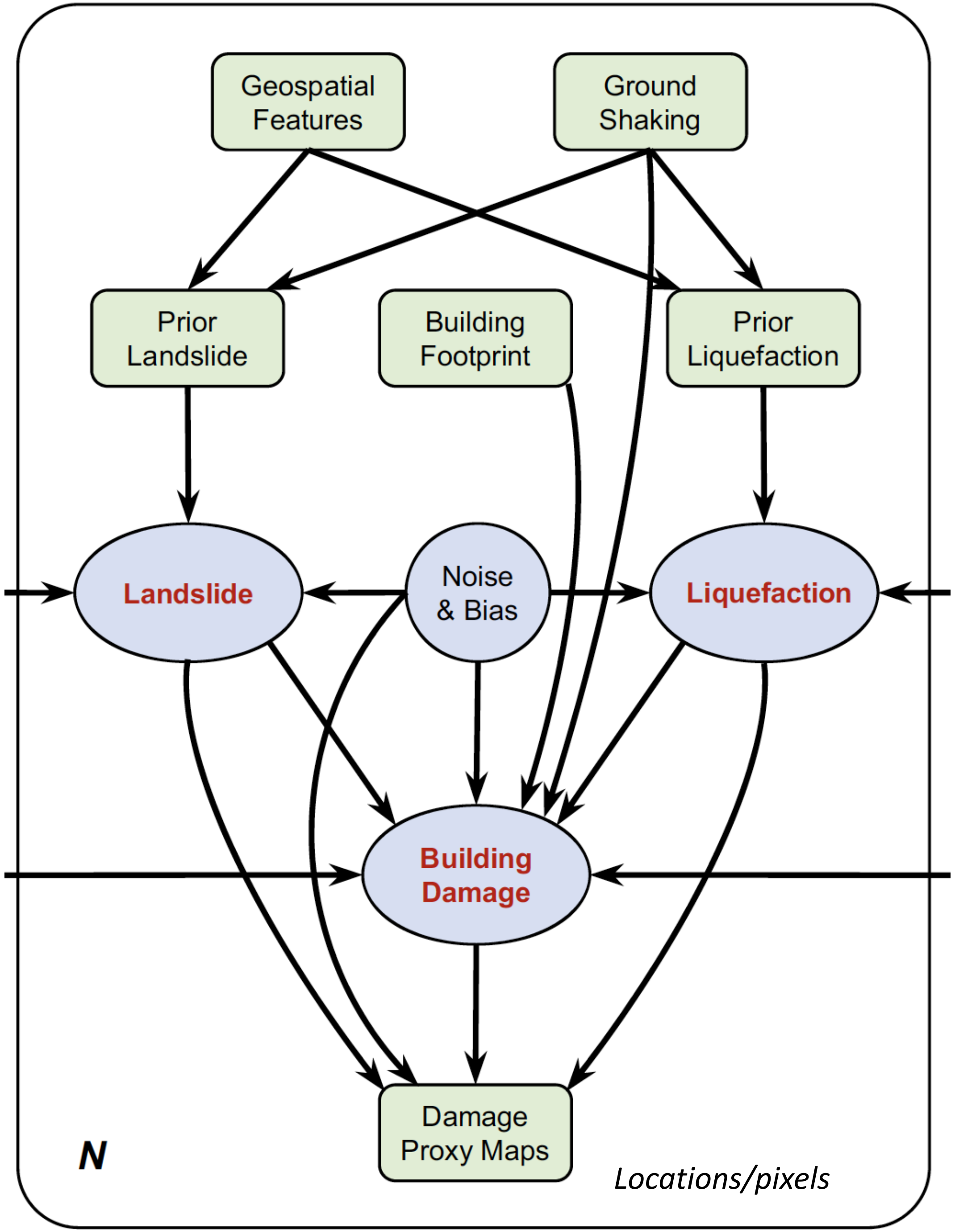
Over the past years, researchers have developed various methods to estimate post-disaster hazards and impacts by providing their spatial distributions of occurrence probability in the disaster zone. These methods fall into two categories:

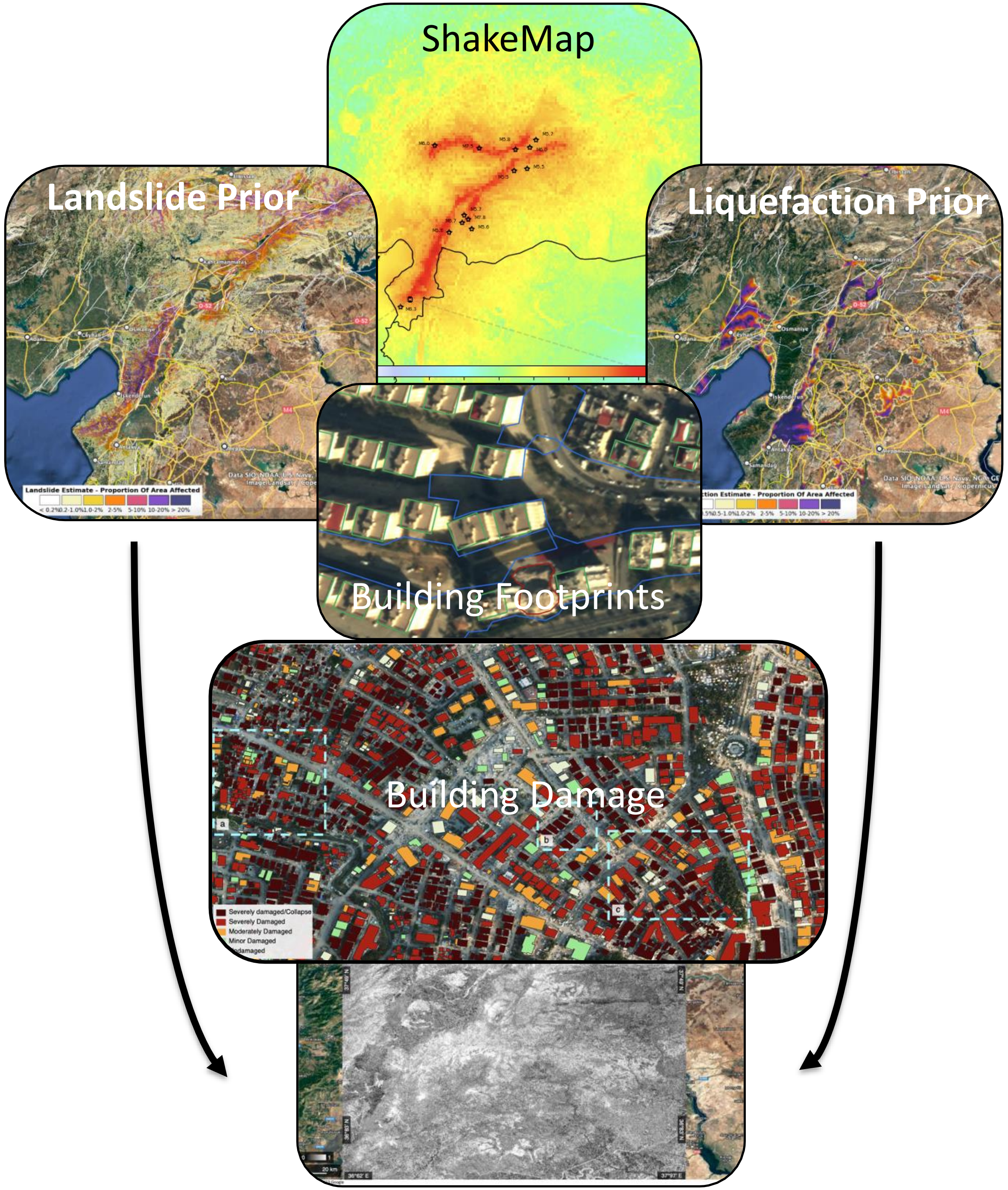
Bayesian Causal Graph with Variational Inference —

A framework for hazard & impact updating



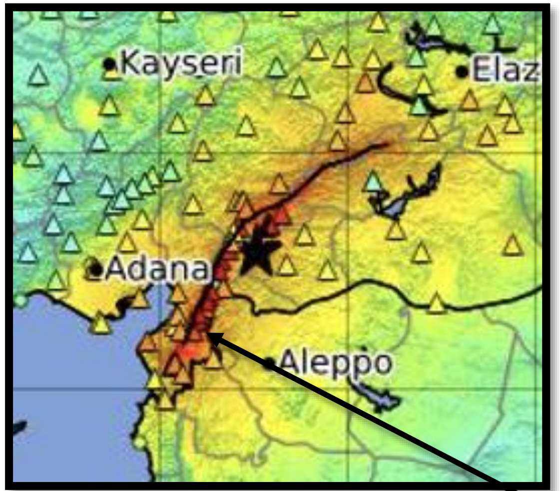
Xu, Dimaska, Wald, & Noh (2022)
Nature Communications


Geospatial Features
Ground Shaking
Prior Landslide
Building Footprint
Prior Liquefaction
Landslide
Noise & Bias
Liquefaction
Building Damage
Damage Proxy Maps
N
Locations/pixels

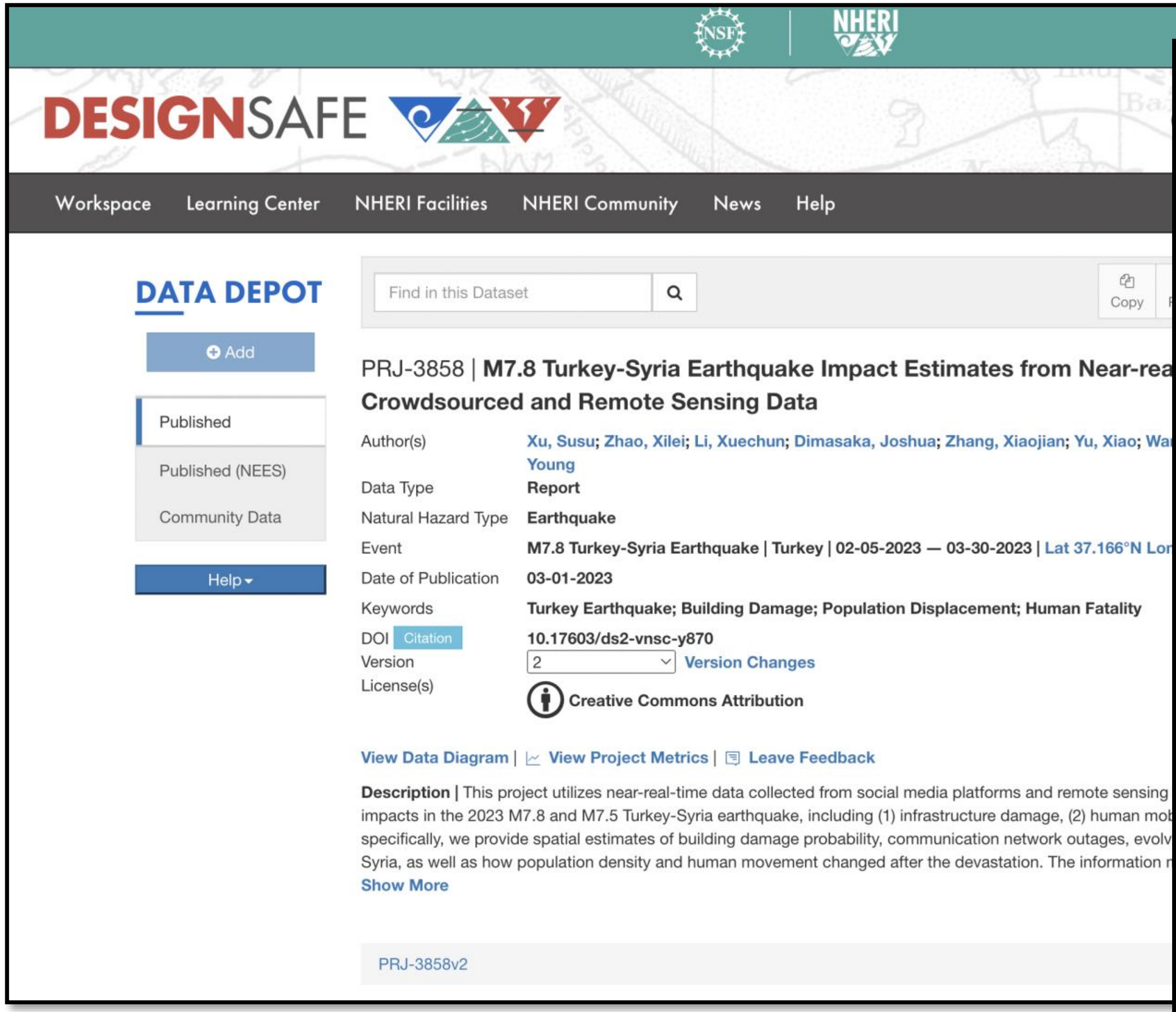

ShakeMap
Landslide Prior
Liquefaction Prior
Building Footprints
Building Damage
Severely damaged/Collapse
Severely Damaged
Moderately Damaged
Minor Damaged
Undamaged

🟫 Severely damaged/Collapse
🟥 Severely Damaged
🟧 Moderately Damaged
🟩 Minor Damaged
⬜ Undamaged

Hatay City



Xu et al, 2023, NHERI
DesignSafe Disaster Portal



PRJ-3858 | **M7.8 Turkey-Syria Earthquake Impact Estimates from Near-rea**
Crowdsourced and Remote Sensing Data

Author(s)	Xu, Susu; Zhao, Xilei; Li, Xuechun; Dimasaka, Joshua; Zhang, Xiaojian; Yu, Xiao; Wa Young
Data Type	**Report**
Natural Hazard Type	**Earthquake**
Event	**M7.8 Turkey-Syria Earthquake | Turkey | 02-05-2023 — 03-30-2023 |** Lat 37.166°N Lon
Date of Publication	**03-01-2023**
Keywords	**Turkey Earthquake; Building Damage; Population Displacement; Human Fatality**
DOI Citation	**10.17603/ds2-vnsc-y870**
Version	2 Version Changes
License(s)	**Creative Commons Attribution**

View Data Diagram | View Project Metrics | Leave Feedback

Description | This project utilizes near-real-time data collected from social media platforms and remote sensing
impacts in the 2023 M7.8 and M7.5 Turkey-Syria earthquake, including (1) infrastructure damage, (2) human mob
specifically, we provide spatial estimates of building damage probability, communication network outages, evolv
Syria, as well as how population density and human movement changed after the devastation. The information r
Show More

PRJ-3858v2

Example comparisons of the building damage prediction with ground truth optical image in Hatay, Turkey, 2023 M7.8

From Xu et al, 2023*, NHERI DesignSafe Disaster Portal

Shaking & Loss Model Overview