DEVELOPING CASUALTY AND IMPACT ALERT PROTOCOLS BASED ON THE USGS PROMPT ASSESSMENT OF GLOBAL EARTHQUAKES FOR RESPONSE (PAGER) SYSTEM

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ABSTRACT

With the advent of the USGS Prompt Assessment of Global Earthquakes for Response (PAGER) system, domestic (U.S.) and international earthquake responders are reconsidering their automatic alert and activation levels as well as their response procedures. To help facilitate rapid and proportionate earthquake response, we describe two potential alerting criteria. One, based on the estimated direct cost of damage is suitable for domestic events; the other, based on estimated ranges of fatalities, is appropriate for global events. The rational for a dual approach for earthquake alerting and response stems from the recognition that relatively high fatalities, and commensurate injuries and homelessness, dominate in countries where vernacular building practices typically lend themselves to high collapse and casualty rates, and it is these impacts that set prioritization for international response. In contrast, often it is financial and overall societal impacts that trigger the level of response in regions or countries where prevalent earthquake resistant construction practices greatly reduce building collapse and associated fatalities. Independent of the criteria, whether financial-loss or casualty-based driven, any newly devised alert protocols must be intuitive and consistent with established lexicons and procedures. In this analysis, we make an attempt at both simple and intuitive color-coded alerting criterion; yet, we preserve the necessary uncertainty measures by which one can gauge the likelihood for the alert to be over- or underestimated.

1. INTRODUCTION

Neither earthquake magnitude nor macroseismic intensity provides sufficient information to judge the overall impact of an earthquake. While larger magnitude earthquakes have greater energy release and can affect a much larger area, losses depend heavily on the exposure and vulnerability of a population to specific levels of shaking. Earthquakes have highly variable effects on society; the complex and variable nature of the effects for differing events can be attributed to a number of contributing factors, primarily the highly variable nature of the hazard distribution (predominantly, shaking intensity), the population exposure, the vulnerability of the built environment, and the resilience of the communities affected. While these factors can now, in part, be rapidly assessed following significant earthquake disasters, communicating the impact is hampered by the lack of an appropriate lexicon.

Currently, NEIC provides automatic alerting capabilities for all significant earthquakes around the world primarily with the Earthquake Notifications Service (ENS; Wald et al, 2008a). ENS presents fundamental improvements for USGS earthquake alerting in that the users can completely customize their alerting levels based on magnitude and location (hypocenter), time of day, and receive messages on multiple devices or electronic addresses (each with, potentially, different triggering criteria) nearly instantaneously. ENS alerts go to over 140,000 subscribed users ranging from critical responders, NGOs, governments, the media, as well as individuals (see Wald et al, 2008a). However, despite the benefits of ENS over earlier list-servers, the alerting criteria are currently limited to magnitude- and location-based triggers. While well-informed users can take advantage of earthquake magnitude, depth, and location to make informed alerts, and possibly analyze losses, most users do not have enough experience nor expertise to tie these parameters to the geographic region (indicating its vulnerability and population exposure) to confidently assess the potential impact. In addition, one must either be conservative by setting a low magnitude trigger level to not miss significant events (and potentially get more alerts than desired), or alternatively, take the risk of missing an important event by setting a higher threshold.

Our proposal here is to utilize the PAGER system to develop an alerting protocol that moves beyond magnitude and hypocenter to provide a more meaningful assessment of what most critical users need to know in order to make response decisions: overall earthquake impact. Since impact assessments can now be done in a quantifiable fashion in near real-time, we explore the potential for using these quantities to initiate alert levels and protocols. Having quantified impacts from a large number of past earthquakes under the auspices of the PAGER system, our approach here is simply to set thresholds consistent with response levels needed for past events for the automated assignments of levels for future earthquakes.

As an important aside, critical users already have another option for alerting based on potential earthquake impact. ShakeCast, short for ShakeMap Broadcast, is a freely available, post-earthquake situational awareness application that automatically retrieves earthquake shaking data from USGS ShakeMap; it then compares intensity measures against users' facilities, sends notifications of potential damage to responsible parties, and generates facility damage maps and other web-based products for both public and private emergency managers and responders (for details see Wald et al., 2008b). ShakeCast is meant primarily for critical lifeline utilities operators in areas where rapid and robust ShakeMaps are available, for example, in California. However, it is operational globally, with higher uncertainty in the shaking estimates than for those maps constrained by numerous seismic stations (see Wald et al., 2008c).

We are aware of the difficulties in changing long-held notions of earthquake severity tied to magnitude and location. However, we now have the capacity to provide more informative post-earthquake situational content and alerts. Rapid diffusion and acceptance of new innovations typically succeeds when the technology and appearance are not only familiar and intuitive but also require little modification of established protocols; in addition, there must also be little technical overhead in order to implement significant changes (e.g., Rogers, 2003). We make an attempt at an alerting scale that is both simple and intuitive. However, given the need to provide uncertainty measures associated with our alerts, we are stepping into an area that has a poor track record in annals of, at least, public communication. Fortunately, some progress has been made in the direction of intensity-based hazard and impact inculcation via USGS products like ShakeMap and "Did You Feel It?".

2. EXISTING NATURAL HAZARD SCALES

The need for systematic earthquake alerting protocols stems from two primary goals. First, timely response at the appropriate level requires an overall impact assessment and an objective description of its impact. Currently, there is no systematic way to rapidly qualify or quantify earthquake disasters other than difficult to make independent measures that include magnitude, casualties, and financial losses. Secondly, the development of the PAGER system, which now automatically provides population exposure and fatality estimates, but lacks the tools for systematically comparing and alerting users of the degree of such impacts from earthquake to earthquake. We can gain some insight into the essential issues related to alerting by examination of recent improvements to existing scales for other natural hazards.

Many existing hazard and societal impact scales exist, and several have become standards for alerting and response protocols. An important limitation, however, is that while many existing scales are useful in quantifying the specific hazard, they do not address the real or potential human impact of the hazard. For example, the *Saffir-Simpson Scale* (wind speed scale from 1-to-5) has universal appeal to describe hurricane winds, but what counts for hurricane mobilization and response is the ability to assess potential impact of various wind speeds and the nature of the built environment at the actual point of landfall. Likewise, predicting the *Enhanced Fujita Scale* level for tornado damage is useful for describing the potential for or measuring tornado wind speeds, yet whether or not a tornado hits or misses a populated area is what determines whether or not a disaster actually occurs. For both, hazard is divorced from impact and the impact is only assessed after post-disaster reconnaissance. The limited utility of other such hazard-based scales for describing impact is common for other natural hazards.

For earthquakes, currently, earth scientists use two scales to measure the size of an earthquake or the severity of the shaking that it produced. These two scales are, respectively, magnitude (e.g., Richter scale, moderized as Moment magnitude) and intensity (e.g., the Modified Mercalli scale). Again, neither scale provides sufficient information to judge the overall impact of the earthquake. While larger magnitude earthquakes have greater energy release and proximity to an earthquake source generally increases the earthquake-shaking intensity, impact depends highly on the exposure and the overall vulnerability of a population to specific shaking levels.

One relatively new scale that crosses from hazard into impact is the National Oceanic and Atmospheric Administration's (NOAA) Northeast Snowfall Impact Scale (NESIS). NESIS combines metrological indices (snowfall amount) with exposed population to rank storms in one of five categories. The ranking provides an indication of a storm's potential impact on local and national transportation and the economy. Like NESIS, PAGER now automatically estimates the number of people exposed to severe ground shaking and the shaking intensity at affected cities (Wald et al., 2008d). Accompanying maps of the epicentral region show the population distribution and estimated ground-shaking intensity. A regionally specific comment describes the inferred vulnerability of the regional building inventory and, when available, lists nearby historic earthquakes and their effects.

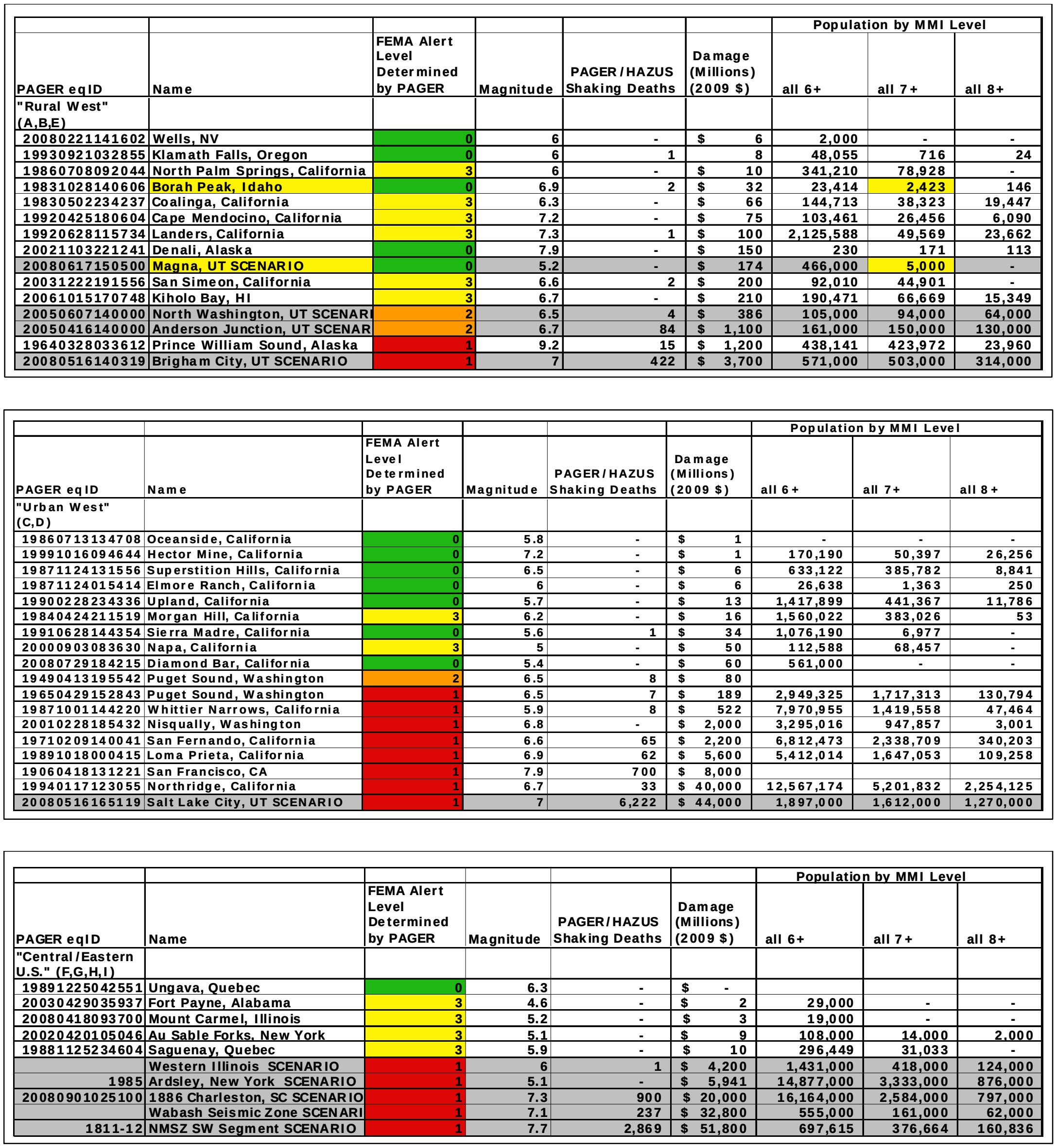
While the primary goal of PAGER is to rapidly estimate injuries, fatalities and, potentially, the financial impact of an earthquake, a succinct method to portray the overall impact and the confidence in this assessment does not exist. To that end we will combine the essential information required in the immediate post-earthquake decision-making environment into a single color-code alert level accompanied by a simple, but quantitative assessment of the uncertainty. Domestically, the PAGER system does not yet directly compute financial losses; we use population exposed as a function of intensity and regional vulnerabilities as a proxy for losses from analyses of past events. Internationally, both a mean estimate of casualties and a description of the possible range of casualties given the uncertainty in the estimates are vital data for any responder to assess the situation.

One caution on the use of new-found alerting scales comes from recent efforts at international pandemic and domestic terrorism alerts. The World Health Organization (WHO) maintains and regularly updates a 6-point scale for pandemic alerts. The WHO will have to rethink the criteria for calling a flu pandemic; currently, only the distribution of the outbreak is considered. Following WHO's level 5 pandemic alert for the 2009 swine flu episode, concern arose that its pandemic alert scale has no mechanism to reflect the fact that a flu pandemic might cause mild, moderate or severe illness and trigger varying levels of societal disruption, WHO will have to consider impact as well as exposure. Again, impact is controlled not only by variations in the severity of the hazard but by the vulnerability of the population exposed.

For man-made hazards (e.g., terrorism), another tale of caution comes from the US Department of Homeland Security (DHS) terrorism alert levels, or Homeland Security Advisory System. The "terror alert level" has five color-coded alert levels, consisting of "low, guarded, elevated, high, and severe", respectively. While designed to guide protective measures when specific information is received about terrorism, it seems to be permanently relegated to an elevated or a high level. Additionally it has received relatively poor marks for overall usefulness. Caveats aside from these examples, there is clearly a strong need for a better post-earthquake response alerting lexicon.

3. DOMESTIC U.S. EARTHQUAKE ALERTING

Domestically, the Federal Emergency Management Agency (FEMA) and other response agencies and organizations are moving beyond magnitude and location-based triggers alone to automatic response activation based on PAGER's near real-time estimates of intensity and population exposure, which is a better proxy for potential impact. FEMA needs to make rapid decisions as to what activation levels are implemented for the National and Region Response Coordination Centers (NRCC and RRCC). Significant forward looking response planning in response to the Post-Katrina Emergency Reform Act of 2006 (PKEMRA), entails activating pre-scripted mission assignments and specific earthquake-response actions depending on the initial activation level. FEMA uses three response activation levels: Level I (catastrophic impacts), Level II (significant impacts), and Level III (considerable damage) for rapidly activating resources. FEMA's response activities require pre-determined executions to address the first several hours of a major earthquake to expedite assistance. FEMA territories consist of 10 Regions and 3 Divisions (East, Central and West); Level I initiates response from resources in the two closest divisions; Level II activates response of all resources in the respective division; Level III triggers resources in the respective region. Activation levels need to be appropriate for different geographic regions since overall earthquake vulnerabilities as well as response capabilities vary from one region to another.



						Population by MMI Level		
PAGER eqID	Name	FEMA Alert Level Determined by PAGER	Magnitude	PAGER / HAZUS Shaking Deaths	Damage (Millions) (2009 $)	all 6+	all 7+	all 8+
"Rural West" (A,B,E)								
20080221141602	Wells, NV	0	6	-	$ 6	2,000	-	-
19930921032855	Klamath Falls, Oregon	0	6	1	8	48,055	716	24
19860708092044	North Palm Springs, California	3	6	-	$ 10	341,210	78,928	-
19831028140606	Borah Peak, Idaho	0	6.9	2	$ 32	23,414	2,423	146
19830502234237	Coalinga, California	3	6.3	-	$ 66	144,713	38,323	19,447
19920425180604	Cape Mendocino, California	3	7.2	-	$ 75	103,461	26,456	6,090
19920628115734	Landers, California	3	7.3	1	$ 100	2,125,588	49,569	23,662
20021103221241	Denali, Alaska	0	7.9	-	$ 150	230	171	113
20080617150500	Magna, UT SCENARIO	0	5.2	-	$ 174	466,000	5,000	-
20031222191556	San Simeon, California	3	6.6	2	$ 200	92,010	44,901	-
20061015170748	Kiholo Bay, HI	3	6.7	-	$ 210	190,471	66,669	15,349
20050607140000	North Washington, UT SCENARI	2	6.5	4	$ 386	105,000	94,000	64,000
20050416140000	Anderson Junction, UT SCENAR	2	6.7	84	$ 1,100	161,000	150,000	130,000
19640328033612	Prince William Sound, Alaska	1	9.2	15	$ 1,200	438,141	423,972	23,960
20080516140319	Brigham City, UT SCENARIO	1	7	422	$ 3,700	571,000	503,000	314,000

						Population by MMI Level		
PAGER eqID	Name	FEMA Alert Level Determined by PAGER	Magnitude	PAGER / HAZUS Shaking Deaths	Damage (Millions) (2009 $)	all 6+	all 7+	all 8+
"Urban West" (C,D)								
19860713134708	Oceanside, California	0	5.8	-	$ 1	-	-	-
19991016094644	Hector Mine, California	0	7.2	-	$ 1	170,190	50,397	26,256
19871124131556	Superstition Hills, California	0	6.5	-	$ 6	633,122	385,782	8,841
19871124015414	Elmore Ranch, California	0	6	-	$ 6	26,638	1,363	250
19900228234336	Upland, California	0	5.7	-	$ 13	1,417,899	441,367	11,786
19840424211519	Morgan Hill, California	3	6.2	-	$ 16	1,560,022	383,026	53
19910628144354	Sierra Madre, California	0	5.6	1	$ 34	1,076,190	6,977	-
20000903083630	Napa, California	3	5	-	$ 50	112,588	68,457	-
20080729184215	Diamond Bar, California	0	5.4	-	$ 60	561,000	-	-
19490413195542	Puget Sound, Washington	2	6.5	8	$ 80			
19650429152843	Puget Sound, Washington	1	6.5	7	$ 189	2,949,325	1,717,313	130,794
19871001144220	Whittier Narrows, California	1	5.9	8	$ 522	7,970,955	1,419,558	47,464
20010228185432	Nisqually, Washington	1	6.8	-	$ 2,000	3,295,016	947,857	3,001
19710209140041	San Fernando, California	1	6.6	65	$ 2,200	6,812,473	2,338,709	340,203
19891018000415	Loma Prieta, California	1	6.9	62	$ 5,600	5,412,014	1,647,053	109,258
19060418131221	San Francisco, CA	1	7.9	700	$ 8,000			
19940117123055	Northridge, California	1	6.7	33	$ 40,000	12,567,174	5,201,832	2,254,125
20080516165119	Salt Lake City, UT SCENARIO	1	7	6,222	$ 44,000	1,897,000	1,612,000	1,270,000

						Population by MMI Level		
PAGER eqID	Name	FEMA Alert Level Determined by PAGER	Magnitude	PAGER / HAZUS Shaking Deaths	Damage (Millions) (2009 $)	all 6+	all 7+	all 8+
"Central / Eastern U.S." (F,G,H,I)								
19891225042551	Ungava, Quebec	0	6.3	-	$ -			
20030429035937	Fort Payne, Alabama	3	4.6	-	$ 2	29,000	-	-
20080418093700	Mount Carmel, Illinois	3	5.2	-	$ 3	19,000	-	-
20020420105046	Au Sable Forks, New York	3	5.1	-	$ 9	108,000	14,000	2,000
19881125234604	Saguenay, Quebec	3	5.9	-	$ 10	296,449	31,033	-
	Western Illinois SCENARIO	1	6	1	$ 4,200	1,431,000	418,000	124,000
1985	Ardsley, New York SCENARIO	1	5.1	-	$ 5,941	14,877,000	3,333,000	876,000
20080901025100	1886 Charleston, SC SCENARIO	1	7.3	900	$ 20,000	16,164,000	2,584,000	797,000
	Wabash Seismic Zone SCENARI	1	7.1	237	$ 32,800	555,000	161,000	62,000
1811-12	NMSZ SW Segment SCENARIO	1	7.7	2,869	$ 51,800	697,615	376,664	160,836

Table 1. Domestic earthquakes and population/intensity exposures used to determine correlation with financial loss-based alerting levels (color-coded, corresponding to levels in Figures 1 and 2). Those marked “scenario” use current population exposure and HAZUS-estimated losses.

Based on PAGER intensity-population exposure estimates for the past 35 years of U.S. earthquakes derived from the ShakeMap Atlas (Allen et al., 2008) and EXPO-CAT (Allen et al, 2009), and by comparison with actual or estimated damage as well as activation levels implemented for these events, we were able to recommend activation levels based on only three geographic regions: Urban Western, Rural Western, and Central/Eastern U.S. In the central and eastern U.S., where actual loss data from recent earthquakes are limited, we supplemented small, recent events with ShakeMap scenarios, PAGER exposure estimates, and Hazards U.S. (HAZUS) damage estimates to determine the appropriate activation levels. The study sample size consisted of 33 damaging U.S. historic events from ShakeMap Atlas going back to 1964 (17 in "Urban West",11 in "Rural West", 5 in Central and Eastern U.S). In addition, we generated HAZUS loss estimates for 10 earthquake scenario events modeled using HAZUS and ShakeMap in areas lacking historic earthquake losses and FEMA responses. With the HAZUS MR-2 release, ShakeMap-specific modifications were made to accommodate ShakeMap input directly ("ShakeBetas"; Kircher, 2002) based on observed losses for the Whittier, Loma Prieta and Northridge earthquakes. Since those three events, credible loss estimates have been calculated using HAZUS for many recent earthquakes since 2004: Parkfield, CA (2004, $2M non-structural); Kiholo Bay, HI (2006, $190M total economic);Wells, NV (2008, $6M non-structural); Mt. Carmel, IL (2008, $3.5M non-structural); Diamond Bar, CA (2008, $90M non-structural no casualties). Examples of population exposed as a function of intensity in PAGER calculations are shown in Figure 3 for both a real (Northridge) and scenario earthquakes.

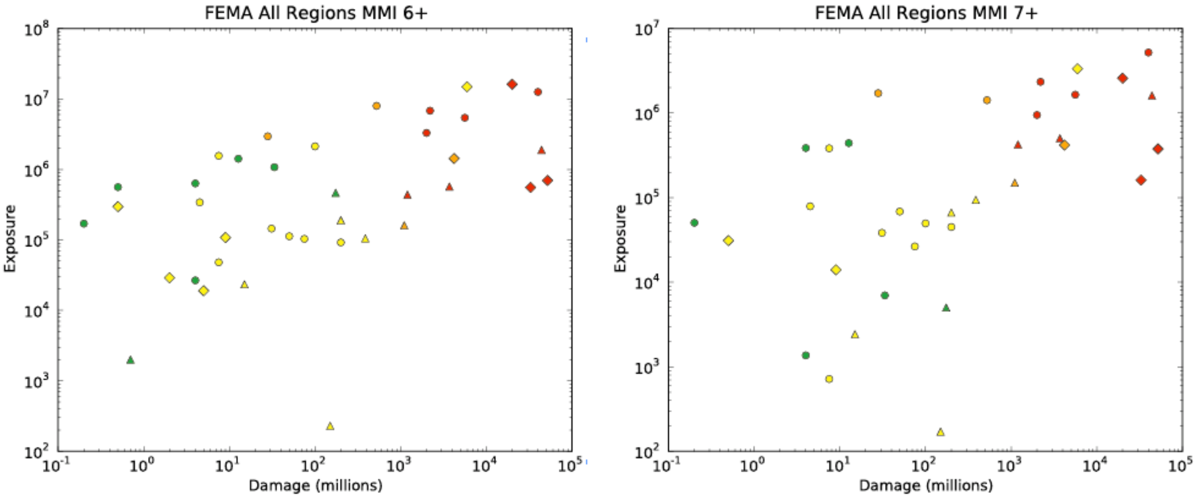
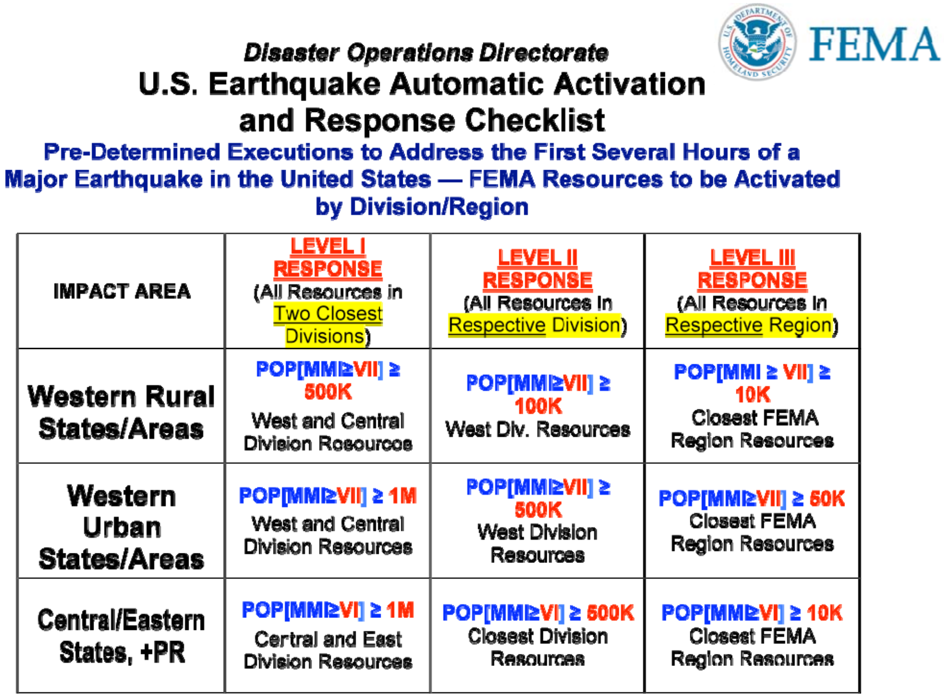


Figure 1. Population exposure to intensity VI (Left) and intensity VII (Right) as a function of earthquake damage in dollars. Green symbols constitute no FEMA activation; yellow, orange, and red symbols constitute Level III, II, and I responses, respectively. Data come from a combination of estimated exposures, actual losses, and assumed activation levels for damaging US events in the past 35 years, plus nearly a dozen scenario events with estimated exposures, HAZUS generated losses, and activation levels. Triangles, circles and diamond symbols represent events in the Western Rural, Western Urban, and Central/Eastern US, respectively (see Figure 2).

The estimated population exposure and damage in millions of dollars for each event analyzed are summarized in Table 1, and plotted in Figure 1. We examined correlations of population exposure with MMI VI and higher and MMI VII and higher (we assume equivalence of instrumental intensity from Wald et al., 1999, and MMI) to determine which would provide more robust alert levels in different regions. We generally consider events with damage greater than $1B to be red alerts; events exceeding $100M achieve orange alerts, and those over $10M are deemed yellow alerts. Although there are many potential criteria for U.S. earthquakes, using MMI levels VI and VII and population exposures ranging from 10 thousand to 1 million were sufficient for providing relatively robust activation levels in most cases (see Figure 1) with rather general population exposure levels set of the three regions (Figure 2). The current threshold activation levels should continue to be adjusted, although they appear to work well for Level 1 and for the majority of Level 2 and 3 activations. FEMA has been advised that when the exposure levels are near the alert trigger thresholds, there is considerable uncertainty in the choice of the alert level, and that PAGER revisions will potentially require reexamination of the alert level.

If and when the PAGER system moves to near real-time financial loss estimates directly, these activation levels could be migrated to using these losses directly rather than population and intensity exposure as a proxy. At that time, uncertainty in the alerting scheme could be addressed. With too few hard data for separating domestic alert thresholds, we cannot yet establish reasonable uncertainty criteria.



Disaster Operations Directorate

U.S. Earthquake Automatic Activation and Response Checklist

Pre-Determined Executions to Address the First Several Hours of a Major Earthquake in the United States — FEMA Resources to be Activated by Division/Region

IMPACT AREA	LEVEL I RESPONSE (All Resources in Two Closest Divisions)	LEVEL II RESPONSE (All Resources In Respective Division)	LEVEL III RESPONSE (All Resources In Respective Region)
Western Rural States/Areas	POP[MMI≥VII] ≥ 500K West and Central Division Resources	POP[MMI≥VII] ≥ 100K West Div. Resources	POP[MMI ≥ VII] ≥ 10K Closest FEMA Region Resources
Western Urban States/Areas	POP[MMI≥VII] ≥ 1M West and Central Division Resources	POP[MMI≥VII] ≥ 500K West Division Resources	POP[MMI≥VII] ≥ 50K Closest FEMA Region Resources
Central/Eastern States, +PR	POP[MMI≥VI] ≥ 1M Central and East Division Resources	POP[MMI≥VI] ≥ 500K Closest Division Resources	POP[MMI≥VI] ≥ 10K Closest FEMA Region Resources

Figure 2. FEMA's proposed Activation Levels for specified population exposures at either intensity VI or VII. See text for details.

4. INTERNATIONAL EARTHQUAKE ALERTING

Internationally, in the immediate aftermath of an earthquake, the impact is first and primarily described in terms of fatalities. We retain this fundamental measure of impact, not because responding to fatalities is relevant, but because this quantitative measure is demonstratively indicative of other critical impact measures demanding response, including non-fatal injuries, homelessness, and overall economic impact. By setting fatality levels within logarithm-based domains (1-10; 10-100; 100-1,000; 1,000-10,000+ fatalities) we can set alert levels that amount effectively to local, regional, national, and international response mobilization, respectively. From a response perspective, fatality-based alerts can simplify and improve decision-making, which is normally based on more limited parameters—traditionally, simply magnitude and location—the combination of which provide relatively poor correlations with actual impacts, except in the simplest of cases.

As shown in Figure 4, the location of the median fatality estimate *e* points to the position within the alert level and is color coded to the alert level color, yielding further indication of the position of the median value with respect to the alert level boundaries (Figure 4). Additionally, we can use the following algorithm for determining the alert levels and their uncertainties (for details, see Jaiswal et al., 2009). In general, the median instead of the mean is often used to designate the central value of a lognormal random variable which associates with 50% of the total occurrence probability. PAGER uses a log-normal distribution to quantify uncertainties in its fatality estimates. Given this distribution, the probability P of the actual deaths (d) being in a particular fatality range a to b is computed (Eqn. 1) using the cumulative distribution function Φ where e is the estimated deaths and ξ is the standard deviation of normally-distributed log-residual error (logarithmic ratio of estimated death and recorded deaths).

$$P(a < d \le b) = \Phi\left[\frac{\log(b) - \log(e)}{\xi}\right] - \Phi\left[\frac{\log(a) - \log(e)}{\xi}\right] \tag{1}$$

For alert level purposes, *a* to *b* are the logarithm-based domains that constitute the alert levels, and thus the probabilities for each alert level naturally constitute the likelihood that the actual number of deaths is outside the alert level associated with the median fatality estimate (Figure 4). For example, the variations in fatality estimated and the corresponding alert scales for the three scenario earthquakes shown in Figure 4 are indicative of the variations in losses for similar magnitude events near several very large global cities; the fatality range could vary greatly depending on particulars of the vulnerability and fault proximity even for similar-sized earthquakes. The histogram on the left side of the Figure 4 plots allows users to gauge how close to adjacent alert levels the median value is, as well as the probability that the alert is in other fatality (alert) ranges.

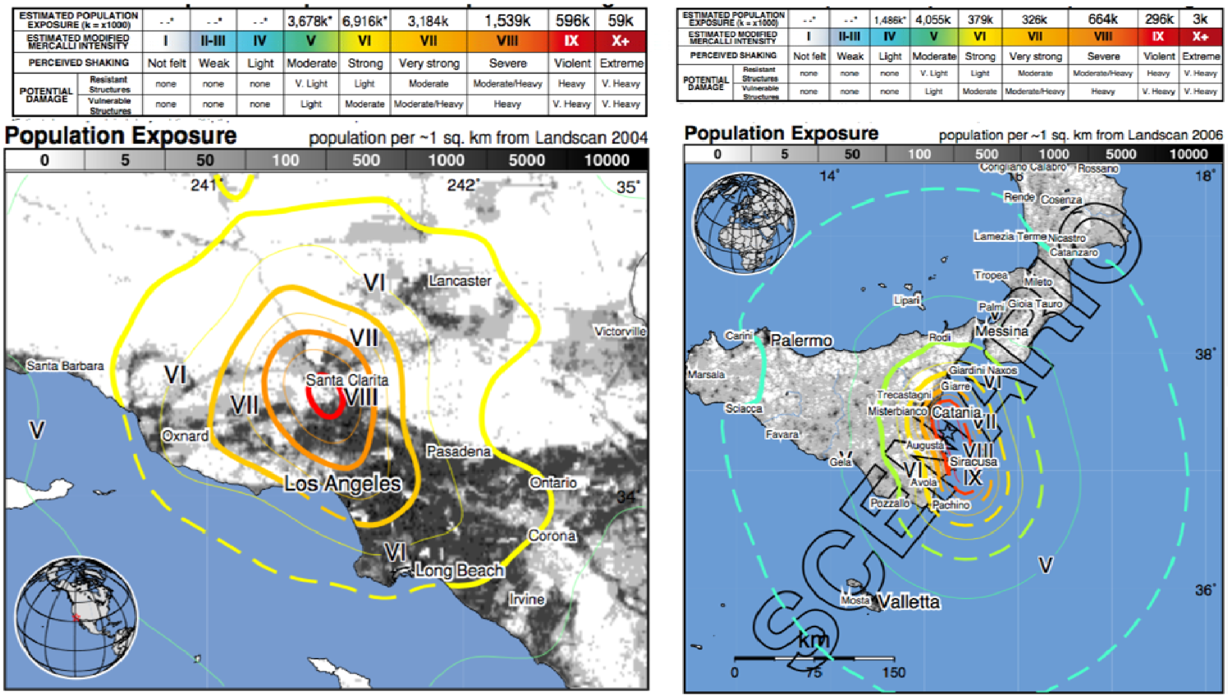


Figure 3. Example PAGER population exposure maps, with color-coded contours of intensity (dashed lines are ½ intensity units), for a the 1994 Northridge, CA, earthquake (left) and a magnitude 7.0 scenario earthquake near Catania, Sicily (right). The estimated total population per intensity level is shown atop the figures.

Note that the likelihood of alerting at the wrong level is greatest in the middle range of estimated fatalities: On the lower end of the median fatality estimates, only higher fatalities could lead to different response efforts; on the highest end, lower estimates are possible but it is unlikely that lower response efforts are requisite. In the middle range, inherent uncertainties can result in either over- or under-prediction of potential response levels. For this reason, users must be cognizant of the potential for revised alerts as further data and information become available. Also note that the PAGER system has three parallel fatality estimate models (empirical, semi-empirical and analytical) depending on the regional data available (e.g., Porter et al., 2008; Wald et al., 2008d); as we refine estimates to be a combination of their appropriately-weighted median values, the alert level uncertainties will also be combined. We anticipate the combined loss models approach will reduce some of the uncertainties associated with the fatality estimates.

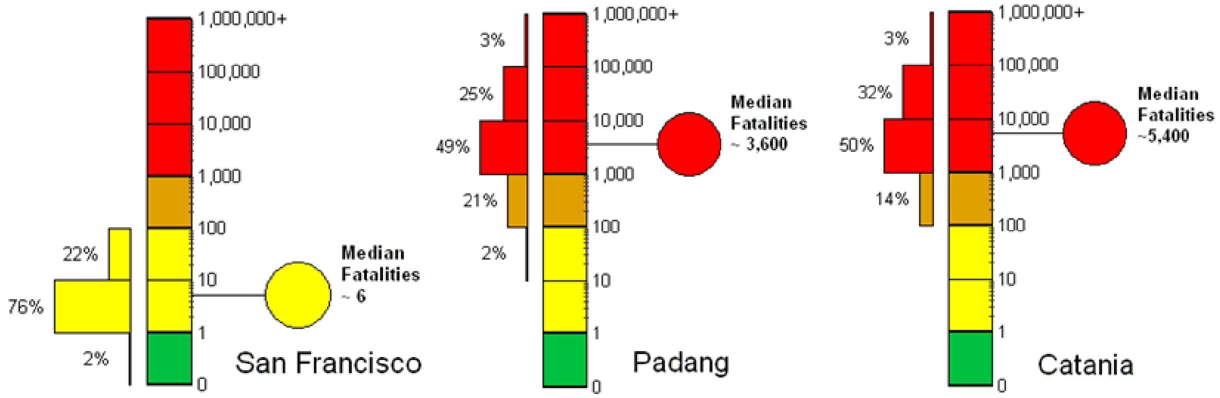


Figure 4. Example of the PAGER fatality-based alert scale for three magnitude 7.0 scenario earthquakes near San Francisco, California (left); Pandang, Indonesia (middle); and Catania, Italy (right; also see Fig. 3). The median fatality estimate is shown pointing to the fatality value on the scale, indicating at what level in the alert range the median estimate lies. The uncertainty in the alert level can be gauged by the left histogram, depicting the likelihood that adjacent alert levels (or fatality ranges) occur. Differences in fatality estimates are due to variations in exposure and vulnerability; these differences are hard to gauge in near real-time without PAGER calculations.

5. CONCLUSIONS

We have proposed two criteria for post-earthquake response alerting levels. For domestic (U.S.) events, the estimated direct cost of damage tends to drive the overall response, since fatalities have been relatively low, at least historically, for events that have nonetheless had very significant financial losses. Hence, while emergency response is critical, at the Federal level, the overall response needs are more typically tied to sheltering and housing, insurance claims, community and business continuity, and overall recovery. We have recommended an alerting scheme based on three US regions, and three levels of population exposure versus intensity to serve as proxies for estimated damage.

These intensity/exposure calculations, and therefore the alerting, can be done within a few tens of minutes of an earthquake in the US, often much faster, and thus may provide the initial basis for response management. Indeed, this approach was motivated by evolving sophistication at FEMA in predefining post-disaster protocols and understanding the hazard and impact levels that would trigger each response level. Other domestic agencies and organizations will benefit from these alerting protocols. Our initial domestic intensity/exposure-based alert levels represent work in progress, and there are insufficient data to provide uncertainties in our alert levels at this juncture.

Internationally, we have set alert levels based on PAGER's median estimate of fatalities. Using a log(fatalities) and choosing subjective thresholds, we have set alert levels associated with yellow (1-10 fatalities), orange (101-1000 fatalities), and red (>1000 fatalities) alerts to be at ranges of fatalities—and commensurate societal impacts—appropriate for what we deem to be regional, country-wide, and international level responses, respectively. The median fatality estimate is used on the earthquake fatality scale to indicate proximity to the alert level boundary, and formal uncertainty in the level is portrayed by providing the likelihood of the actual value of fatalities being in adjacent fatality (and thus alert level) ranges. From 1973 to 2007, the years that comprise EXPO-CAT, and given the fatality-based alerting protocol recommended here for global earthquakes, there would have been 5,000 green, 490 yellow, 51 orange, and 48 red alerts. Red alerts were comprised of 34 events with greater than 1,000 fatalities and 14 events with greater than 10,000. Over that time period there were approximately 14 yellow, 1-2 orange, and 1-2 red alerts per year (Figure 5).

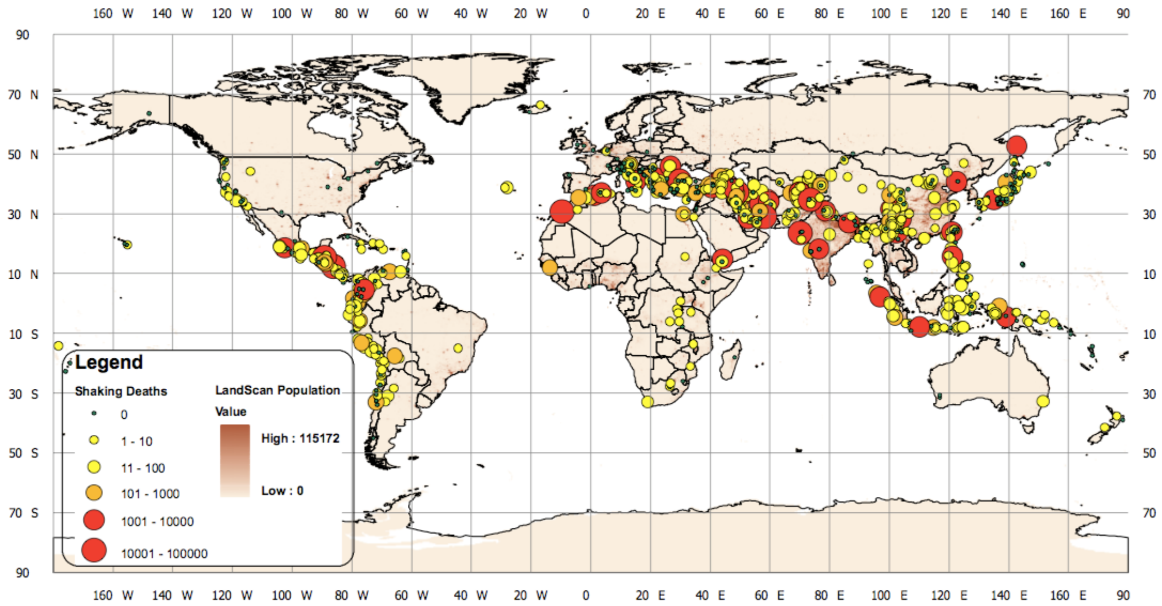


Figure 5. Map of fatality-based alert levels that would be triggered given the observed fatalities for events in the PAGER EXPO-CAT (Allen et al., 2009). The legend provides the fatality threshold for color-coded alert level. Over the past forty years there would have been about 5,000 green, 490 yellow, 51 orange, and 48 red alerts (approximately 14 yellow, 1-2 orange, and 1-2 red alerts per year.

In this discussion, we have focused on alerts based on the median estimate of fatalities associated with shaking damage, primarily building collapse. Marano et al. (2009) separate out the main secondary causes of fatalities for earthquakes over the past roughly 40 years, and find that while shaking-related deaths dominate overall, specific events can have a significant proportion of fatalities caused by secondary effects (specifically, landslide, fire, and tsunami). Since these tend to cluster geospatially, we add specific messages associated with our PAGER summaries that alert users to the potential for such secondary impacts. The loss of life caused by secondary effects are yet included in the PAGER loss estimation models quantitatively, but the qualitative statements PAGER automatically provides have proven useful for several important cases including the 2008 Sichuan, China earthquake where nearly ¼ of the fatalities were due to landslides.

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