Adding Secondary Hazard and Ground-truth Observations to PAGER's Loss Modeling

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ABSTRACT

A rapid, holistic view of earthquake disasters begins with earthquake location and magnitude, alerted by seismic networks. The initial source characteristics, along with any available ground-shaking observations, can be used to rapidly estimate the shaking extent, its severity (e.g., ShakeMap), and its likely impact to society, for example, employing the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response, or PAGER, system. When serous impacts are likely, PAGER's impact-based alerts can, in turn, begin the process of primary response at the local, national, or international level, and the process of reconnaissance via social media, the mainstream media, scientific analyses, and remotely-sensed and ground-truth observations. In this work-in-progress report, we describe our initial efforts to incorporate event-specific ground-truth observations and model secondary ground-failure hazards back into the loss-modeling domain in order to provide a more holistic view each earthquake disaster.

Keywords

Keywords: PAGER, ShakeMap, ShakeCast, earthquake damage, earthquake losses

INTRODUCTION

The initial step in developing a holistic response to an earthquake disaster is recognizing that one has just occurred. In September 2010, the USGS began publicly releasing earthquake alerts for significant earthquakes around the globe based on estimates of potential casualties and economic losses with its PAGER system. Quantifying earthquake impacts and communicating estimated losses (and their uncertainties) to the public, the media, humanitarian, and response communities required a new protocol, necessitating the development of an Earthquake Impact Scale now deployed with the PAGER system. After two years of PAGER-based impact alerting, we have reviewed operations, hazard calculations, loss models, alerting protocols, and our success rate for recent (2010-2012) events. This review prompts analyses of the strengths, limitations, and opportunities, allowing clearer definition of future research and development priorities for the PAGER system.

Among the important avenues of research and development identified for PAGER, two that are being actively pursued align with the notion of a holistic assessment in the immediate post-earthquake time frame. First, we are incorporating secondary hazard assessments with the ultimate goal of adding the capability of estimating losses and guiding response considering both landslides and liquefaction. Second, we are debating how best to incorporate post-earthquake ground-truth observations back into the loss-modeling domain. For instance, if one has an observation of the minimum number of fatalities 24 hours after an earthquake, and the number is larger than that initially estimated by the loss model, does one modify the estimate?

Incorporating loss observations back into the loss-modeling domain is fraught with pitfalls. Real-time Bayesian updating of the model used for loss estimates, for example, would be difficult, since the loss models are fairly robust (an informative Bayesian prior). In contrast, initial single-event hazard and loss data are unlikely to be more credible than those used in the model development, and establishing their credibility is difficult. Continued refinements to the earthquake source (its hypocenter, magnitude, and fault dimensions) and thus updates to the shaking-hazard estimates are routinely used to update loss calculations. For example, any ground motions recordings or internet-based, crowd-sourced macroseismic intensity observations that come in from the USGS "Did You Feel It?" system (Wald et al., 2012) that come in are used. However, preliminary damage observations themselves are not currently used to update the loss model; typically, by the time credible, stable loss data are available, the usefulness of the PAGER loss model has passed. If essence, once ground-truth data are widely available they should take precedence over loss modeling.

Directly utilizing loss or impact observations could be complicated. Loss observations in the immediate post-earthquake environment are highly uncertain, so changing the prior model is risky. More often then not, early loss assessments grow with time (for instance, fatality totals increase with additional reconnaissance and ground-truth observations), so employing preliminary observations would often reduce the quality of the initial, potentially unbiased, estimates. And, determining at what point the ground-truth observations are stable, or are at least beneficial in terms of an improving the initial loss estimate, will always be challenging.

Further, does one even attempt to update initial loss-model estimates, or should the initial models be quickly or gradually supplanted by ground-truth observations, recognizing that indeed the model estimate's utility is in the immediate aftermath of the event? And, that the loss-model estimate's short shelf life is really a manifestation of their uncertain nature? Naturally, sound observations for a new event ought to be added back into the model for recalibration at a later time, but should this be done in near-real-time? Since the operational loss model used for PAGER alerting is empirical (e.g., Jaiswal and Wald, 2012a,b), clearly there is room for improved interplay between model-based and ground truth observations. Thus, here we report on efforts to improve early loss models by incorporating remotely sensed deformation and damage-proxy maps as well as newly-developed models for assessing the extent and severity of landsliding and liquefaction.

PAGER OVERVIEW

PAGER divides impact assessment into four primary modules: earthquake source characterization, shaking hazard estimation (via ShakeMap), exposure and loss estimation, and lastly, communicating uncertain hazard and impact information rapidly, robustly, and coherently. These four PAGER modules have been developed in an open environment. Data, models, and outputs are all documented online, via peer-reviewed publications, and/or USGS Open-File Reports. Valued intermediate and final data and products used in creating PAGER loss estimates, including the ShakeMap hazard grid, are publically shared and are accessible in near-real-time.

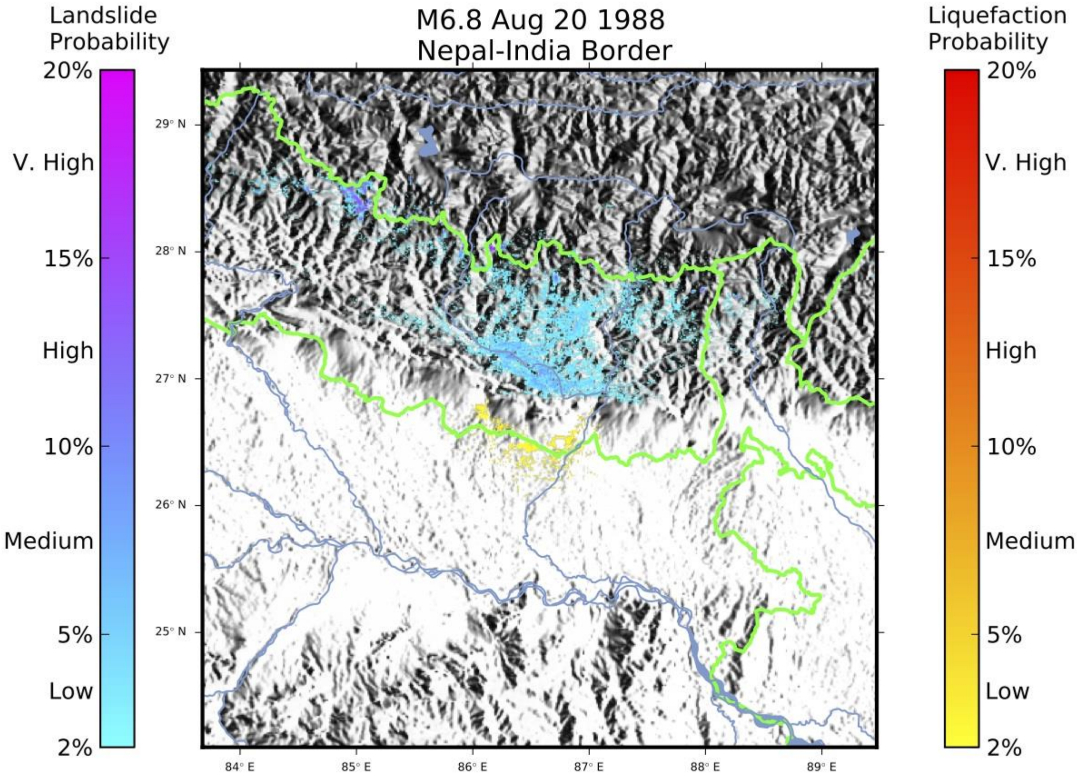
The PAGER system takes a ShakeMap as the primary hazard input. After establishing the hazard base layer, we estimate losses. We resample our ShakeMap grid to the same size as 2010 LandScan 1x1-km global population data grid to get estimates of both population and shaking metrics at each cell. The current operational PAGER system employs country-specific fatality and economic loss curves that are functions of exposed population per intensity level, derived using analyses of losses due to recent and past earthquakes (Jaiswal et al., 2012a,b). In some countries, our empirical loss models are informed in part by PAGER's semi-empirical and analytical loss models, particularly their building exposure and vulnerability data sets, both of which are have been developed in parallel to the empirical loss-estimation approach (Jaiswal and Wald, 2012a,b).

To facilitate rapid and appropriate earthquake responses based on our probable (and uncertain) loss estimates, in early 2010 we proposed a four-level Earthquake Impact Scale (EIS; Wald et al., 2010). Instead of simply issuing median estimates for losses—which can be easily misunderstood and misused—this scale provides ranges of losses from which potential responders can gauge expected overall impact from strong shaking. Alert levels are characterized by alerts of green (little or no impact), yellow (regional impact and response), orange (national-scale impact and response), and red (international response). Corresponding fatality thresholds for yellow, orange, and red alert levels are 1, 100, and 1000, respectively. For damage impact, yellow, orange, and red thresholds are triggered when estimated US dollar losses reach 1 million, 100 million, and 1 billion+ levels, respectively. Critical users receive PAGER alerts based on the EIS-based alert level, in addition to or as an alternative to magnitude and population/intensity exposure-based alerts, and optionally, for only user-selected regions of the world. Accompanying text clarifies the nature of the alert based on experience from past earthquakes and provides context on the total economic losses in terms the fraction of the Gross Domestic Product (GDP) of the country affected. The summary also provides regionally specific *qualitative* information concerning the potential for secondary hazards, such as earthquake-induced landslides, liquefaction, and tsunami.

INCORPORATING LANDSLIDE AND LIQUEFACTION ESTIMATES IN PAGER AND SHAKECAST

As noted above, PAGER currently provides *qualitative* advisory statements pertaining to the likelihood of secondary perils for each earthquake alerted based on the region and past earthquakes there. For example, every event is checked against our database of losses for the country of interest, and if landslides, liquefaction, fire following, or tsunami losses were common historically, PAGER's messaging lists those perils as potential additional contributors to losses not directly accounted for in PAGER's shaking-based estimates. Thus, although the PAGER and ShakeCast systems are capable of estimating losses in near-real-time from the shaking-based hazards, they do not currently provide impact estimates due to these ground failure (or secondary) hazards. Moving forward, we are using the ShakeMap hazard layer to more *quantitatively* assess both the likelihood and spatial distribution of ground deformation hazards.

Specifically, Zhu et al. (2013) and Nowicki et al. (2012) have proposed analogous statistical models for estimating liquefaction and landslide distributions, respectively, that make use of ShakeMap outputs, and were calibrated against historical ground deformation case histories. Globally available susceptibility variables include topographic slope, geology, Vs30, distance to rivers, and compound topographic index (CTI). We have now implemented and are testing the reliability of these preliminary landslide and liquefaction models for use in ShakeCast and PAGER. Figure 1 shows, for one event selected out of the ShakeMap Atlas, our initial approach for visualizing landslide and liquefaction hazard extent and likelihood, and thresholds are derived that indicate their overall severity (to be used in alerting).



Landslide Area	863 km²
# of cells	55,017
Maximum probability	22.5%
Mean probability	2.0%
Minimum slope	5.0°

Liquefaction Area	109 km²
# of cells	55,017
Maximum probability	7.3%
Mean probability	1.7%
Maximum slope	5.0°

Figure 1. Landslide and liquefaction probability map for the M6.8 August 20, 1988 Nepal-Bihar earthquake. Cool colors represent landslide probability and warm colors represent liquefaction probability.

An ongoing challenge entails developing methods to accommodate small-scale maps using global data sets as predictor variables for PAGER maps, with aggregate hazard and loss estimates, yet employing more accurate methods when site-specific geotechnical data are available (e.g., in the USGS ShakeCast, which treats losses at specific facilities; see Lin and Wald, 2008). Adequately assessing the sensitivity of secondary hazard maps given the use of global proxy data sets, and making near–real-time aggregate loss estimates from these maps will require considerable further research and development.

INCORPORATING GROUND-TRUTH OBSERVATIONS

One fundamental reason for the necessity of systems like PAGER is that ground-truth observations are highly variable in quality, content, and temporal availability. Sometimes conditions on the ground make the situation clear and obvious. More often than not though, complicating factors adversely affect information flow; these factors include the overall scope of the disaster, darkness of night, lack of electricity and communication, and the lack of awareness of impacts in remote regions. Hence, the quality, speed, and content of damage data vary tremendously and are highly situation-dependent. Yet, near-real-time reporting of damage from earthquakes has rapidly evolved and improved. The global reach of social media, crowdsourcing, and 24x7 internet and broadcast journalism provide ample opportunity for very rapid reporting. While expert curating of such content is a must, in many cases these sources can rapidly shed light on complex, evolving disasters. Currently, the PAGER team follows a wide range of information sources following earthquakes, yet we do not make direct use of these constraints for PAGER loss modeling. Instead, we focus on rapidly improving our hazard constraints, which do affect our loss estimates, but we let the ground-truth observations take precedence over our loss estimates as they become more reliable. Determining when, which sources, and what content constitute reliable loss information is a complex matter in its own right. One source of crowd-sourced information we do employ regularly for ShakeMap constraints, and thus for PAGER input, as mentioned earlier, are data from the USGS "Did You Feel It?" (DYFI) system. While DYFI data, too, warrant caveats, such concerns have been addressed systematically in Wald et al. (2012).

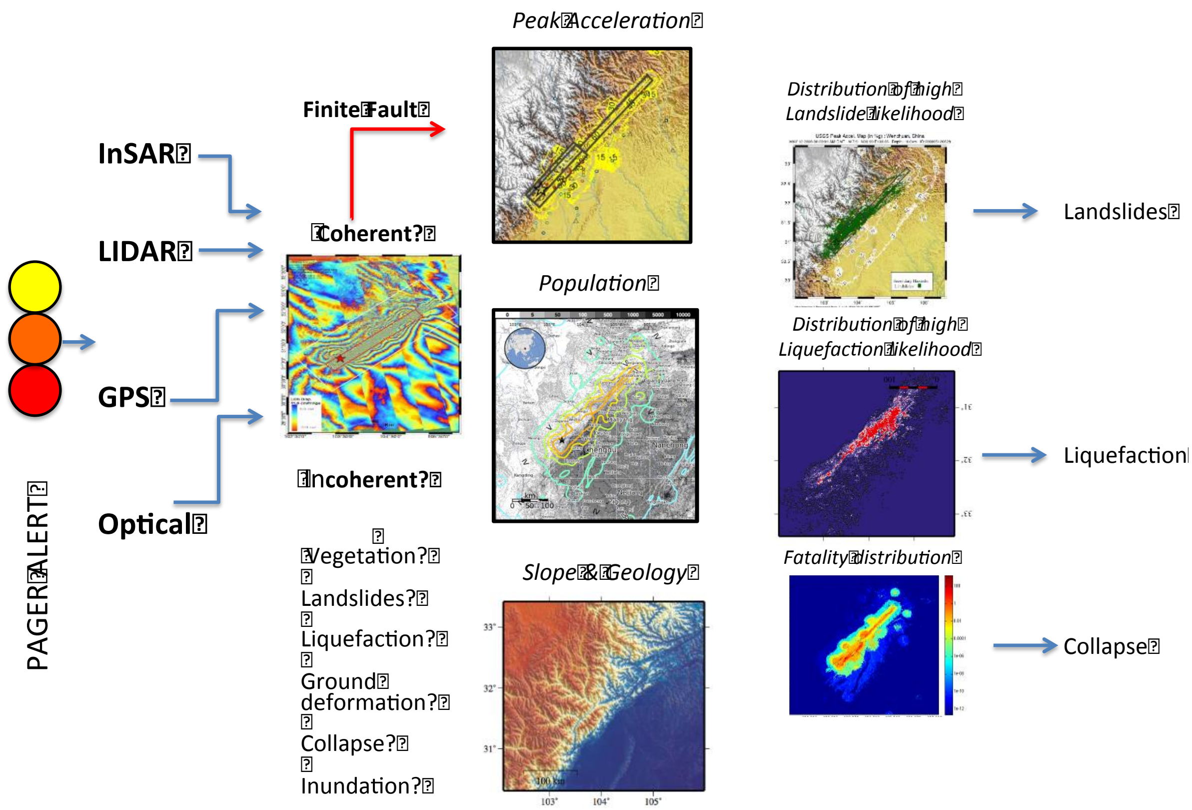


Figure 2. Schematic strategy for incorporating remote-sensed imagery and global-proxy data sets into ShakeMap/PAGER for rapid hazard estimation and loss assessment.

INCORPORATING REMOTELY-SENSED OBSERVATIONS

A more rigorous source of post-earthquake data comes from remote sensing. Opportunities abound for combining remotely sensed building inventory with ground truth losses after earthquakes, though currently data latency is still problematic for many purposes, including for use in PAGER. Nonetheless, under the auspices of the Advanced Rapid Image for Analysis (ARIA) project, the PAGER team is collaborating with scientists at Caltech and NASA's Jet Propulsion Laboratory (JPL) in efforts involving post-earthquake spatial analyses of both optical and radar imagery, which both use pre- and post-earthquake image differencing to infer ground deformation and other sources of change, including landslides, liquefaction, and building damage. This promising arena entails significant challenges in rapidly and automatically updating model-based loss estimates with observationally based assessments of damage. A conceptual depiction of the strategies being explored is shown in Figure 2.

The overall goal is to combine what is known from the ShakeMap and PAGER databases with real-time loss assessments to determine the most likely source of imagery correlation at any location. In some cases, coherent fringes in the InSAR image can be attributed to long-wavelength ground deformation resulting from ground displacement, or even incoherent images proximal to the fault rupture. Faulting information can be then be directly used for better constraining shaking in ShakeMap, since site-to-fault distance is an important parameter when estimating ground shaking. Often, however, the source of the image complexity must be deciphered from multiple possible sources. This presents both a challenge and an opportunity.

For example, as depicted in Figure 2, if the region is very steep and of low population, the source of imagery changes is likely landsliding; in contrast, changes in flat areas with low populations and high liquefaction susceptibilities may be attributable to liquefaction. Alternatively, in flat areas with high populations and high building vulnerabilities, changes may be attributed to building damage. In this sense, it becomes clear that the spatial distribution of landslide and liquefaction probabilities (Figure 1) for an earthquake can serve as a filter for attributing pre- and post-earthquake image changes to ground deformation. Adding PAGER building inventory databases combined with loss estimates will further help sort out such remotely sensed observations. Once attributed to a logical source, these images can be considered "damage proxy maps" (Yun et al., 2013). A critical aspect of the damage proxy map is that the locations of all features are extremely accurate since optical and InSAR imagery are both spatially highly accurate. Thus, if one can determine the cause of image change, its exact location is known. Such accurate spatial resolution combined with PAGER model-based loss estimates may prove to be extremely valuable for more accurately pinpointing secondary hazard and damage locations after earthquake disasters.

CONCLUSION

In its current state, PAGER is an extremely useful tool for understanding the scope of a potential disaster both to initiate response and to begin reconnaissance in the minutes and hours after an earthquake. Though we do not currently employ observed losses gathered in rapid, post-earthquake earthquake forensic analyses, we are developing other ways to contribute to holistic, post-earthquake situational awareness. Two specific goals outlined in this *work-in-progress* report aim at improving PAGER's loss-modeling capabilities in related realms. First, by adding the capability to estimate ground deformation (particularly landsliding and liquefaction), we address a difficult, neglected yet often serious source of secondary earthquake losses and which can complicate response. The capability to estimate ground deformation, in turn, improves our ability to address the second area of interest: we are developing tools to accommodate remotely-sensed data, that, due to its high spatial accuracy, may lead to much better resolution of the location of damage and ground failure if we can ascertain whether pre- and post-earthquake images differences are attributable to landsliding, liquefaction, or building damage. PAGER is a work in progress, and while there are still some technical and data-related challenges, there are also many opportunities to improve PAGER's capabilities so that it remains an essential tool in the realm of early impact estimation and contributes more towards a holistic view during earthquake disasters.

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