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FINANCIAL DECISION-MAKING BASED ON NEAR–REAL-TIME EARTHQUAKE INFORMATION

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Abstract

Post-earthquake financial decision-making has evolved considerably over the past decade. Insurers and reinsurers, private companies, governments, and aid organizations have shown increasing creativity in the use of near-real-time (NRT) earthquake information for their own loss estimation, financial adjudication, and situational awareness. Such financial analyses can be of significant benefit to stakeholders, facilitating risk transfer operations, fostering sensible management of risk portfolios, and assisting disaster responders. The main motivation for this paper is the elucidation and documentation of how existing and developing post-earthquake financial decision-making strategies make use of or depend on NRT earthquake information. A better understanding of the tools of the trade and specific needs of the financial sector can further enhance NRT earthquake information systems, which in turn may enhance the further development of creative financial instruments, resulting in additional beneficial risk management alternatives for at-risk communities. The advancement of post-earthquake financial instruments has been, in great part, made possible by the availability of rapid and accurate earthquake parameters and more quantitative geospatial hazard information. For example, the U.S. Geological Survey's (USGS) earthquake information systems have evolved to further accommodate specific requirements, some particular to the financial sector. Herein, we describe several developments that streamline post-earthquake financial decision-making, primarily related to the USGS ShakeMap system. In particular, we discuss improvements to 1) event-specific metadata, data and product archiving, and technical documentation; 2) additional gridded parameters (including interpolated rock-motion estimates); and 3) improved ground motion reporting, including spatial variability characterization and enhanced directivity functions. Lastly, we describe the systematic collection of scenarios and historical ShakeMaps; they too facilitate the calibration of loss models and hindcasting.

Keywords: ShakeMap; Earthquake losses; Post-earthquake financial decisions; Catastrophe (cat) bonds; Cat models

1. Introduction

There are three general categories of post-earthquake decision-making workflows that today require detailed near–real-time (NRT) earthquake hazard input: 1) rapid assessment of damage to guide disaster response and aid deployment; 2) estimation of monetary loss to a portfolio of industrial, commercial, or residential exposures to guide the deployment of insurance adjustors and the payment of the associated claims; and 3) the triggering of so-called parametric transactions—insurance instruments that rely on the physical measurement of event characteristics to determine whether the insured party receives compensation and how much.

In fact, the role of NRT earthquake reporting tools has evolved from merely informational to one of increasing strategic value and even to one of critical responsibility in the exchange of large capital amounts in the financial markets. Note also that while all the roles enumerated above have the common purpose of assessing the consequences of an earthquake, the usage of NRT tools has been customized according to the particular needs of the users. For instance, business and public sector portfolio managers may employ tools like USGS ShakeCast or other in-house loss-estimation applications to automatically retrieve earthquake parameters from the USGS and compute losses based on pre-assigned or customized fragility curves. In the (re)insurance industry, where since the 1980s the usage of catastrophe (Cat) models [1] has become increasingly commonplace, earthquake parameters and ground-motion footprints can be used to build probabilistic scenarios of loss. These capabilities have enhanced the ability of insurers to fine-tune claims payment strategies and to make early important financial decisions to secure the necessary capital and facilitate response (claims payment) capabilities. Further, loss models now in frequent use in the industry have been calibrated using the data stored by the USGS and other earthquake data providers. While not orthodoxly used in "NRT mode," these datasets originally arise from the NRT networks designed and maintained by seismological and geological survey agencies worldwide.

Given the often proprietary nature of Cat models and other financial instruments, the iterative process of scientific research and development on the NRT earthquake systems front has been somewhat blind to their usage. Nonetheless, well-informed feedback and numerous reasonable requests for particular products or software features related to financial instruments have been accommodated over the years, and this has helped guide our efforts. By sharing a perspective at the frontier between researchers and users, it is the aim of this paper to foster collaboration opportunities that in turn inspire further creative risk-management solutions.

The paper is roughly divided into two parts. In the first, we provide a brief background and overview of existing insurance and alternative risk transfer strategies that make use of NRT earthquake information systems, presenting a series of illustrative examples of current applications. Franco [2] provides a comprehensive background concerning insurance-related earthquake mitigation strategies. The discussion in the first part of this paper is an attempt to dig deeper into the subset of those strategies that rely on NRT earthquake hazard information systems. In the second part, we describe recent developments on ShakeMap and other related USGS post-earthquake information systems, such as the ShakeCast and Prompt Assessment of Global Earthquakes for Response (PAGER), that will further facilitate the refinement and use of innovative financial decision-making tools and instruments.

Current and potential financial decision-making capabilities associated with Earthquake Early Warning (EEW) systems [3] or Operational Earthquake Forecasting (OEF; e.g., [4]) are not covered in this paper, although we expect that significant related innovations will also appear on these fronts. Nor do we specifically address the targeting of specific trades or market positions. We also expect that a number of additional proprietary post-earthquake financial products and capabilities—not promoted or publicly detailed—likely escaped our attention; so the authors encourage other financial and Cat experts to provide feedback to help fill any knowledge gaps.

2. Post-Earthquake Financial Strategies and Instruments

Estimated losses constitute vital input for rapid situational awareness, facilitating decision-making on whether or not to commit and deploy resources, and to what extent. For over a decade, the U.S. Department of Homeland Security's (DHS) Federal Emergency Management Agency (FEMA) has used ShakeMap as the shaking hazard input for their HAZUS-MH software. This usage has been the standard procedure to respond to damaging U.S. earthquakes (as well as simulated scenarios) in order to estimate losses and thus to evaluate response and recovery needs. FEMA's economic loss estimates—along with damage observations—have been used to expedite State or Federal disaster declarations. Loss models are naturally useful after major events, yet even after moderate domestic (U.S.) earthquakes, hidden but costly losses are nearly invisible to remote-sensed or casual (drive-by) inspections and can take weeks or months to gauge. Although initially unnoticed, hundreds of millions of dollars (USD) of losses were discovered belatedly following the 2011 Mineral, Va. (M5.8) earthquake, and more recently nearly half a billion USD losses were tallied well after the 2014 South Napa, CA (M6.0) earthquake; the initial loss-model estimates were that high, but actual loss tallies lagged behind by weeks.

PAGER [5] models described such losses within minutes to hours of these events, and HAZUS loss estimates provided more detailed evaluations within a day. In parallel, industry-based loss estimates are computed employing ShakeMap and other hazard inputs, and such results are provided to clients through internal channels and newsletters, and oftentimes to the financial and insurance sectors via the media. Internationally, the PAGER system has routinely provided both an estimate of likely fatalities and overall direct loss estimates since mid-2010. Some financial- and insurance-sector users employ tools like ShakeCast [6] for NRT damage and inspection priority evaluations, as well as for larger financial decisions, including response allocations and expected repair and recovery costs.

A very successful strategy used to assess risk and set market prices comes from the catastrophe risk modeling realm, where several companies (e.g., RMS, AIR, CoreLogic) have developed sophisticated hazard, loss, and risk assessment Cat models over the past two decades. In the earthquake realm, these tools often rely on NRT as well as scenario and historical earthquake parameters—including ShakeMaps—for calibration. Such Cat models can also be used to evaluate specific insured public, private, and commercial portfolios and determine the scope of losses immediately after earthquakes.

More recently, a number of rather innovative post-earthquake financial instruments have started to proliferate and triggered an increasing number of inquiries and requests related to the USGS ShakeMap and other NRT earthquake information systems. To put these financial-decision instruments in context, we provide some nontechnical background (see Table 1). We also aim to illuminate several of the financial sector use categories with specific case histories.

2.1. Insurance Strategies

Earthquake insurance and related monetary compensation tools and instruments play an important role in risk transfer. In turn, risk transfer complements more direct forms of risk mitigation such as stricter building codes and improved infrastructure. Of late, better community resilience has progressed through the promotion of greater awareness of the potential human and economic consequences of earthquakes with adoption of insurance as an important action to be taken. Such policies may cover damages to the built environment, injury, casualty, and business interruption. Both private individuals and companies purchase insurance products to protect their assets and in so doing cede their risk to an insurance company, which effectively acts as a risk aggregator that diversifies the risk across the population. Insurance companies may in turn cede risk to global reinsurance companies, thus providing further diversification.

While indemnity insurance (which aims to provide compensation based on the actual loss) is the most common, non-indemnity-based strategies make up a significant fraction of the market [7]. These rely not on actual losses, but on proxies to losses that may or may not be well-correlated with the actual losses realized. Understanding the potential difference between the payout and the actual losses—referred to as "basis risk"—plays an important role in setting appropriate rates. Many of the rates for premiums and much of the risk written into Cat bonds is determined via models. The calibration and accuracy of these models is highly dependent on NRT and historic earthquake ShakeMaps as well as on long-term probabilistic shaking hazard (PSHA) inputs and assessments [8]. Yet other important considerations come into play when considering how non-indemnity-based instruments are valued and triggered.

Insurance linked securities (ILS) and (re)insurance-linked investment instruments—such as Cat bonds—have attracted institutional investors because of the often-higher yields (in the current market conditions as of fall 2016, this is less of a driver) and because of the diversification and low correlation they provide with traditional markets [7]. Additionally, according to Artemis [7]: "Investors are looking to the ILS market as a new socially and societal responsible investment category, as an asset class that provides essential disaster risk capital after major impactful regional catastrophe or weather events, thus enabling a greater ability to recover from disasters." In this context, catastrophe bonds can serve to transfer capital for disaster-risk financing by those within the capital markets—with the resources to take on these risks—and away from governments, populations, and individuals at risk of severe losses. These transactions can also provide capital in the immediate post-event environment (see the 2016 Ecuador earthquake example, below), not only in order to maintain cash-flow liquidity and to pay claims but also to provide financial stability. After large disasters, the social benefits from such financial pre-planning may also include providing overall confidence and stability of markets in the immediate aftermath of a shaking-induced financial scare.

Cat bonds allow the transfer of a specific set of risks from an issuer (or sponsor) to investors. The sponsors are typically sovereign governments, corporations or, more commonly, insurers or reinsurers themselves. Investors thus carry the risks of specified catastrophes or events occurring, in exchange for attractive (depending on market conditions) rates of return on their investment of capital. Should a qualifying event occur, the investors will lose some or all of the principal they invested and the issuer will receive that money to cover their losses. Cat bonds can thus bring capital from financial institutions into reinsurance operations. Individuals and companies who have investments in hedge funds that purchase Cat bonds are therefore also contributing to the provision of capital for Cat reinsurance (e.g., [2]).

For reference, Cat bonds (usually 3- to 5-year tranches) have reached about 8% of the total global catastrophe reinsurance market [8]. As of 2016, the outstanding Cat bond market is over US$26B (for a full list of parametric earthquake transactions see Acton [8]). Out of about $26B of outstanding principal, roughly $14B includes earthquake risk; trigger types, detailed later, are distributed primarily among indemnity (65%), indexed (30%), parametric (10%), and modeled (less than 5%) [7, 8]. Cat bonds can also be publicly traded and aggregated into dedicated portfolios. In some sense, then, the NRT earthquake information user groups can be considered to include not only the (re)insurance markets but capital markets in general [7]. It is thus natural that the USGS is interested in understanding and documenting as well as interacting with and accommodating this fundamental NRT earthquake information-use sector. So, what exactly are these alternative risk transfer instrument triggers, and what is their dependency on independent seismic source and ground motion parameters?

2.2. Types of Cat Bond Triggers

Whether or not the qualifying event "triggers" a payment is dependent on pre-agreed-upon natural hazard parameters available from an independent reporting agency (NOAA for wind speed; USGS for earthquake magnitude and location, for example). Triggers can be structured in many ways, from a sliding scale of actual losses experienced by the issuer (indemnity) to a trigger which is activated when industry-wide losses from an event hit a certain threshold (industry loss trigger) to an index dependent on the physical characteristics of the event itself (parametric trigger) [8]. As described below (and in Table 1), Cat bond triggers can be grouped into several categories. A number of these triggers depend on independent NRT earthquake information systems both for their creation (trigger specifications) and for obtaining the actual parameters in the immediate aftermath of a potentially triggering event. The immediacy of the parametric triggers and their quick payout is one significant advantage over indemnity-based instruments, which may take months or even years to pay out.

First-Generation ("Cat-in-a-Box") Parametric tools appeared in the early 90s. These instruments base payments not on the direct observed damage, but rather on the independently measurable fundamental parameters of the physical event. Such parametric triggers are a preconditioned agreement between the issuant and claimant on the physical parameters (e.g., magnitude and location of an earthquake) that would constitute a payout. Thus, a prearranged, independent party is required to ascertain the parameters of interest. It is commonplace for USGS earthquake parameters (e.g., magnitude and hypocenter) to be used as the basis for first-generation or "Cat-In-A-Box" parametric Cat bonds. The main advantage of first-generation parametric triggers is that they are very simple to set up and for investors and sponsors to understand. They require little Post-event loss calculation (PELC) since a lookup table often suffices [9], and this makes them probably the fastest triggers in the market. Their rapid payout provides financial liquidity and reduces financial uncertainty. Their main limitation is their high basis risk—the potential gap between the payment and the actual losses—although strategies can be implemented to minimize these errors somewhat [10].

Example: (First-Generation Parametric) The recent US$200M Acorn Re 2015-1 Cat bond is a Western U.S. parametric trigger-based earthquake bond that provides cover for the Kaiser-Permanente corporation [7] for three years. Parts of British Columbia, northern Mexico, and seven western states are in the coverage area, but most of the exposure is in California. The geographic area is divided into one-degree-sided (~110 km) boxes to discriminate events according to their location and magnitude; it has four severity levels triggering variable event-loss percentages. The boundary areas with Canada and Mexico allow for near-U.S. border events that could cause U.S. damage.

Second-Generation Parametric triggers allay some of these high basis risk concerns by considering hazard intensities distributed among a series of locations in the area of the exposed assets, as opposed to just the fundamental characteristics of the event. Parameters frequently used for these transactions consist of recorded or inferred ground motions. Cases in which there is high uncertainty in the exposure distribution could favor first-generation approaches, whereas areas in which reliable networks of seismometers are present and the exposures are well known could lend support to second-generation approaches [2]. In the presence of a reliable seismological network, ground motions can be usually interpolated with confidence at a set of specified locations. Typical metrics include those mapped in the ShakeMap process: namely peak ground accelerations (PGAs), spectral accelerations at specific natural periods, and macroseismic intensity. In order to aggregate the shaking intensities from all the stations or locations involved in the transaction, it is customary to calculate an aggregated value or an index that takes into account the contributions of the geographically dispersed intensities. This index then is used as a proxy for loss of the portfolio of exposed assets. (Oftentimes, second-generation parametric triggers are often referred to as second-generation parametric indices.)

The main benefit of such indices is that—being direct proxies for shaking and thus damage—they potentially provide a better correlation between parametric losses and actual losses than first-generation triggers based on magnitude and hypocenter alone. Yet caution must be exercised when comparing these methodologies, since the uncertainties affecting ground motions used in second-generation parametric indices are typically greater than those affecting the main parameters of the event [2].

Second-generation parametric index Cat bonds typically use shaking values from USGS ShakeMap, either interpolated or directly, or from proximal observed ground motions (in the rare cases where a dense-enough network is available, see example below) in order to establish the value of the index after an event. Modeling losses with ShakeMap as input for indexed triggers is now standard operating procedure. As characterized by

Ramirez [11], "USGS is used as a preferred Reporting Agency to establish event parameters for ILS Transactions". This is echoed by CoreLogic [12]: "All vendors of earthquake risk products use USGS [values] of PGA and MMI."

Table 1. Primer on common shorthand expressions used in the industry. Our definitions provide guidance, but no attempt is made at producing a formal and comprehensive definition of the terms.

Expression	Definition
Basis, or Basis risk	In the context of parametric insurance, refers to the potential difference between the actual losses experienced and the recoveries from a risk transfer instrument. Can be referred to as "positive" if the recoveries are larger than the actual losses and "negative" if the recoveries are smaller than the actual losses.
Insurance pools	A mechanism through which participants regularly contribute to a jointly held fund that is devoted to cover expenses of any of the individual participants who incur losses covered by the pool agreement. An insurance pool is typically operated by a government or by a group of insurers, but it may be operated by a small informal community as well.
Insurance Linked Securities (ILS)	A tradable security, like those transacted in the financial markets, linked to an insurable interest such as a portfolio of assets subject to a potential loss from natural disasters. This mechanism has made it easy for the financial markets to participate directly in insurance operations. The overlapping market formed by finance and insurance is now referred to as the "convergence" market.
Catastrophe or Cat bonds	A particular type of Insurance-Linked Security: a financial tool that meets a series of strict formal requirements in order to be freely tradable alongside other types of bonds by portfolio managers.
Indexed Losses	Losses obtained as a proxy based on an "index" that may be tied to other metrics such as industry-wide losses or losses in certain regions.
Indemnified Losses	The actual losses that are paid to the insured.
Parametric Losses	Losses as determined by a parametric tool, a derivative that relies on physical measurements of some event characteristics or on other parameters to establish the level of recoveries to the insured.
First-generation or Cat-in-a-Box	A type of parametric tool that relies only on the main parameters of an event. For earthquakes, these typically consist of magnitude and hypocenter. Because these tools are documented with the aid of maps, they delineate cells or "boxes" to identify the locations of events that merit payment, thus they are commonly known as Cat-in-a-Box. They are typically discrete, establishing different payment levels for different boxes and magnitudes.
Second generation or parametric indices	Called "second generation" to imply an evolution from the Cat-in-a-Box concept, these instruments use a field of ground motions as parameters and are more continuous, offering a graded payment schedule that varies smoothly with the level of ground motions.
Moral hazard	The risk that one party might bias loss information to its benefit in an insurance transaction—a claimant may exaggerate a loss, and an insurer may downplay it. It is typically cited as an advantage that the moral hazard of parametric insurance mechanisms is low, since all loss information depends on measurements that are provided by an unbiased third party.
Modeled Losses	The losses obtained by using a Cat model, a numerical simulation of a catastrophic event affecting a portfolio, typically computed in a probabilistic Monte Carlo framework or through the application of some deterministic ground motion scenario.
Post-Event Loss Calculation (PELC)	Parametric mechanisms need to be computed according to a series of rules, functions and parameters, previously documented, and agreed (and when appropriate escrowed). This process is referred in the insurance context as Post-Event Loss Calculation and it is typically executed by a technical expert agent that is not a party to the transaction.

Example: (Second-Generation Parametric) Turkey is one of the top catastrophe markets. The Turkish Catastrophe Insurance Pool (TCIP) is a state-backed insurer that currently pools exposure into a Cat bond issued by Bosphorus 1 Re Ltd. [7]. The bond provides three-year reinsurance coverage for Istanbul, Turkey. The parametric trigger employs recorded peak spectral accelerations (PSAs). Bogazici University's Kandilli Observatory and Earthquake Research Institute (KOERI) is the transaction reporting agency. KOERI will provide PSA values for input into RMS's Europe Earthquake Model, based on strong-motion sensor observations from a network of instruments in the Istanbul region. For an event to qualify under the terms of the bond, it must result in PSAs greater than 0.1g for at least 10% of the calculation locations, as confirmed by the calculation agent [7]. As a contingency, if KOERI data are not available after an event, it will source alternative data from the USGS ShakeMap. An innovative feature of this Cat bond is the ability for new calculation locations to be added during the annual resets, potentially allowing TCIP to extend the geographic region that the transaction covers via the inclusion of additional seismic stations outside of the immediate Istanbul region [7].

Other Parametric-Index-based risk transfer tools can be tied to a variety of different parameters. For instance, farmers may use policies against weather-related risks that can be settled based on meteorological occurrences. With index-based insurance, payouts are based on an objectively measured index that is correlated with farmers' losses rather than actual realized losses, thus settlement times are intermediate, somewhere between parametric and indemnity-based losses, typically in the range of months. Index-based insurance can overcome the onerous obstacle of substantiating numerous claims, since indices that represent agricultural risks (including rainfall, yield statistics, and vegetation conditions) can often be measured by satellites [13]. When an index exceeds a certain threshold, farmers receive a fast, efficient payout, in some cases delivered via mobile phone [13]. Although the basis risk can also be high in this case, the amount of risk can be modeled and made commensurate with loss models or statistics. For earthquakes, the parametric-index-based trigger can, for example, be based on the ratio of the population exposed to a predefined shaking intensity level compared to the total population of the country. Such an arrangement would ensure financial coverage for any earthquake for which significant (pre-agreed-upon measures of) shaking levels affect some fraction of the country's population. The payment could be used as deemed appropriate by the issuer country's response and rebuilding needs.

Example: (Parametric Index) The Inter-American Development Bank (IDB) structures sovereign liquidity guarantees (e.g., contingency loans) for natural disasters in seven Latin American countries (Dominican Republic, Honduras, Nicaragua, Costa Rica, Panama, Ecuador, and Peru). A 72-hour turnaround for indexed coverage calculations allows for rapid dissemination of funds without the need for ground-truth assessments. The indexed payout avoids the moral hazard associated with reported losses, but the basis risk may be high: ShakeMap shaking estimates are uncertain, and population exposure per intensity level may be insufficient to adequately characterize actual losses. IDB uses the population exposed to MMI-VI or higher to calculate the guarantee amount to be disbursed (J. Martinez, IDB, written communication, 2015). IDB Contingent Credit Facility Loan triggering is based on USGS ShakeMap and employs PAGER population exposure per intensity level published 72 hours after a significant event. Contingent funding per country is up to $300M USD and loan amounts are initiated for an earthquake with an intensity MMI-VI or greater that has affected at least 2% of the population within the coverage area. It is indexed up to the full amount based on the Coverage index, *CI*: CI = (TAF – P2) * 100 / (P5 - MP2), where *TAF* is the total affected population at the set intensity level of VII, and *P2* and *P5* are 2% and 5% of the country's population, respectively. *Under the auspices of this specific triggered contingency loan, on April 20, 2016, IDB activated a US$300M credit line to support the Ecuadorian government with losses and emergency expenses* [14].

Modeled-Loss triggers, derived from calibrated Cat models, can be used to evaluate the recoveries of a risk transaction. Payouts are based on modeled losses simulated using these models and NRT earthquake information. All Cat model inputs (e.g., earthquake parameters, shaking prediction equations, causative faults, and observed shaking constraints) are carefully vetted and agreed upon in advance, and then NRT information is used to identify the modeled event that most resembles the actual event (or, in some cases, a new synthetic event may be built within the model to represent the actual event). To model potential loss values and set coverage rates, exposure estimates are required. Like parametric triggers, modeled-loss triggers can be settled relatively quickly (in weeks) since the authoritative input parameters are rapidly available. Basis risk is intermediate, between indemnity and parametric, although this obviously depends on the quality of the model used. Indeed, model risk (potential loss error caused by the model itself) is often a barrier in the implementation of these tools.

Example: (Modeled-Loss Trigger) The California Earthquake Authority (CEA) employs ShakeMap for post-earthquake evaluation of liquidity (solvency) for insured losses to California residential properties as well as for situational awareness. CEA guidelines require industry-standard (proprietary) insured loss estimates to report to the State Governor within seven days of any significant earthquake that affects California (B. Patton, oral comm., 2015). CEA also employs ShakeMap for post-earthquake situational awareness via GIS layer GeoJSON feeds in the aftermath of earthquakes. In addition, CEA has supported the development of “General Guidelines for Assessment and Repair of Earthquake Damage in Residential Woodframe Buildings” [15]; the Guidelines (section 9D) set standards for using ShakeMaps for post-event inspection.

Industry-Loss based coverage is based on the fraction or share of a company relative to the total overall losses suffered by the industry as aggregated by an authoritative industry representative. The trigger is typically activated when industry-wide losses from any event reach a certain threshold.

Example: (Industry Loss Trigger): Everest Re issued an US$800M, five-year coverage against exposure to earthquakes in the U.S. and Canada. The trigger itself will be a regional weighted industry loss index based on Property Claims Service (PCS), an insurance claims leader, which reports catastrophe losses for qualifying earthquake events. As reported by Artemis [7], modeling of potential losses by historical events by AIR Worldwide shows that four historic events would have resulted in a 100% reduction of principal.

Indemnity-Loss solutions are triggered by the issuer's actual losses; thus, the sponsor is indemnified just as they would be under traditional insurance or reinsurance. Naturally, indemnity loss triggers are most correlated to the actual losses of the insurer sponsoring the Cat bond, yet they may suffer from potential moral hazards, including the possibility that parties involved manipulate the outcome of the payment mechanism to their advantage [10].

Example: (Indemnity Loss Trigger): Even with indemnity-based triggers, some bonds have additional triggering criteria. For example, Lakeside Re III bond (which covers much of the seismically active regions of Canada, as well as U.S. states including California, Oregon, Washington, and those along the New Madrid seismic zone), has an earthquake peril trigger based on shaking data reported by the USGS. For a trigger, the event must cause ground shaking in the covered area at intensity VI or higher as reported by USGS ShakeMap [7].

We have briefly highlighted some of the tradeoffs among the different types of triggers, their settlement time, and basis risk. ShakeMap ameliorates several of the aforementioned Cat bond triggering concerns and could alleviate others. Recent ShakeMap developments—including improved products, documentation and metadata, and collections of historical and scenario ShakeMaps—may help to further improve these risk transfer solutions that make use, directly or indirectly, of NRT earthquake information systems.

3. Near–Real-time Earthquake Product Developments

Considerable investment and financial resources in recent years have come to rely on earthquake parameters (recorded ground motion amplitudes and ShakeMaps), along with other derivative downstream products including industry loss models, HAZUS-MH, and PAGER. The reliability, consistency, and availability of NRT post-earthquake content now readily available enhances and complements the important role of (significantly improved) Cat modeling, which in turn has greatly expanded earthquake risk transfer [2]. It is thus essential to modify and improve some the processing and earthquake information deliverables and procedures while continuing research and development. Several types of data and information products now available, or under development, may benefit the financial sector (and others). For example, it became clear that better version control and archiving were necessary for escrow and verification purposes [8]. Likewise, other requests have been made for enhanced ShakeMap metadata, including rupture, ground motion prediction equations, and other parameters, as have appeals for grids of parametric uncertainty, bedrock ground motions, and site amplification terms. These and other enhancements are introduced below.

3.1. ShakeMap Software Enhancements, Metadata, and Documentation

Ramirez [11] noted that NRT earthquake parametric data and versions of hazard products get escrowed and that legal documents depend on them. To this end, ShakeMap metadata and documentation have been significantly improved. Initially, the ShakeMap Manual [16] was the authoritative source documentation, but it has been recently superseded by a more dynamic version [17]. Most technological updates to ShakeMap were published via peer-reviewed journals, so the link back to the ShakeMap Manual was slow and circuitous. The revised ShakeMap Manual is now hosted online by GitHub source-control hosting and markdown language (e.g., Sphinx) documentation [17]. This strategy allows the software and associated documentation to be updated in a timely fashion as soon as changes or improvements are implemented. This strategy is part of a modernization of the NRT earthquake information systems developed at the USGS National Earthquake Information Center (NEIC). The ShakeMap, ShakeCast, PAGER, and Did You Feel It? (DYFI) systems are all being updated in parallel in a similar framework. However, any significant scientific enhancements will continue to be vetted and documented via the peer-review process.

Availability of ShakeMap software via GitHub began with the initial beta release of ShakeMap Version 4, referred to as *pyShake*. (As of 2016, most US regional or national seismic systems running ShakeMap are running Version 3.5.) Although ShakeMap has always been open-source, version control for *pyShake* in GitHub will provide users, developers, and other interested parties access to ongoing ShakeMap developments as well as the opportunity to view and participate (e.g., via requests). This development framework is key for collaboration among USGS NRT earthquake information system developers as well as those external collaborators developing related tools on similar platforms (e.g., GEM's OpenQuake engine [18]).

Another common request was more fully vetted metadata, particularly the event-specific configurations, inputs, and outputs. As now described in the Manual [17], the ShakeMap metadata are greatly enhanced and depicted online in human-readable format as well as through live GeoJSON feeds [17], and these files will be available for ShakeMap Atlas [19], scenarios, and recent events. For scenarios, the *info.json* file also provides additional metadata considering directivity function when that function is employed.

Although standard GIS metadata have been provided for over a decade, the improved event-specific information is more aimed at preserving parameters necessary for understanding or replicating each particular map. The metadata are provided in ShakeMap product's *info.json* file, which specifies input constraints (including fault dimensions, ground motion, and intensity data), ground motion prediction equations (GMPEs) employed, and outputs (including maximum shaking values, uncertainty, GMPE bias corrections). Critically, the *info.json* file provides the ShakeMap software, update versions, and timestamps; these timestamps are often required for quality assurance, including for financial escrow and other legal purposes. Previous requests for GIS formats and services were accommodated via specific GIS (e.g., Shapefile and HAZUS-specific) formats for the past decade. More recently, USGS has added Web Mapping Services (WMS), providing ArcGIS formats and metadata for a wide range of GIS users. WMS ShakeMap layers are also provided by the Pacific Disaster Center and ESRI (see Worden and Wald [17] for details and links). For many GIS users, the automatic retrieval and processing of ShakeMaps via GeoJSON feeds and the ShakeCast system provide useful options and alternatives.

It is likely that additional financial decisions and product triggers can be facilitated and automated with these feeds.

INPUTS

Event Information

ID	1134567	Location	12 mi. SE of Desert Hot Springs, CA	Origin Time	Mon Aug 03 12:01:06 PDT 2015
Magnitude	6.2	Longitude	116.2	Mechanism	RS
Depth	6.2	Latitude	16.2	Mechanism source	composite
Flinn Engdahl region	83 - SOUTH OF PANAMA	Tectonic regime	SZintra	Number of seismic stations	141
Fault file(s)	northridge_fault.txt	Fault reference(s)		Number of DYFI stations	43

PROCESSING

ShakeMap Versions

Code	3.5.1440	Map	4
Date	Mon Aug 03 16:03:10 PDT 2015		

Site Response

Reference rock Vs30 (m/s)	686
Site correction applied	Borcherdt table

ROI Table

	ROI (km)	Observation Decay
Ground Motion	10k	0.5
Intensity	10k	0.5

Miscellaneous

Used log amp to compute bias?	yes	Norm of the bias (l1|l2)	l1
Max distance to include station in bias (km)	120	Min # of stations necessary to compute bias	6
Max magnitude to compute bias	7.7	Max allowed bias	2.0
Min allowed bias	-2.0	Outlier level (# of std dev)	3
Maximum magnitude to flag outliers	7.0	Median distance used	no

Ground Motion/Intensity Information

	Module	Reference
GMPE	BA08_old	Boore and Atkinson, 2008
IPE	DefaultIPE	ShakeMap Manual, 2015
GMICE	FM10	Faenza and Michelini, 2010
iGMICE	FM10	Faenza and Michelini, 2010, 2011
Directivity	None	None

Fig. 1 – Snapshot of initial portion of an example ShakeMap metadata file (*info.json*).

3.2. Alternative ShakeMap Realizations

An additional enhancement often sought for ShakeMap-based loss modeling is rendering alternative shaking realizations other than the standard presentation of medium peak (as opposed to geometric mean) ground motions. Improved approaches for quantifying uncertainty can better inform loss estimates, and historical ShakeMap Atlas data can assist in loss model calibration. Although some sophisticated users scale up the ShakeMap median ground motion values with the reported grid uncertainties, that exercise was left to the user. With the recent addition of refined methods for accounting for GMPE-based (empirical) directivity functions and spatial variability, the ShakeMap group is experimenting with providing multiple realizations of each earthquake (scenario, archival, and NRT).

Specifically, source directivity can now be added via the ShakeMap software by employing directivity functions developed under the auspices of the NGA-West2 GMPE development project [20]. At least three realizations will likely be provided per event; specifically, the two unilateral rupture alternatives and the average directivity term. ShakeMap Version 4.0 allows for the use of multiply weighted GMPEs. The strategy for such GMPE use in NRT ShakeMaps is still to be reconciled, since it is complicated by the use of associated GMPE inter-event term bias corrections. Significant efforts have been made [21] to generate a suite of ShakeMap scenarios that accommodate both directivity and multiply weighted GMPEs in an effort to produce a collection of scenarios that are derived from and consistent with the USGS National Seismic Hazard Maps. Further documentation of these developments is provided in the ShakeMap Manual and by Thompson et al. [21]. In addition, implementation and are testing the addition of empirically constrained frequency- and distance-dependent ground motion spatial correlations to ShakeMap is underway. The strategy for presenting them is currently being vetted and documented [23]. Such spatial variations have been shown to be important for portfolio and general loss estimates [22, 23].

3.3. Permanently Archived NRT, Historic and Scenario ShakeMaps

The expansion of the ShakeMap realm beyond NRT maps to include decades of historic earthquakes (ShakeMap Atlas) and hundreds of scenarios warranted a revised archive strategy. Many users, particularly in the earthquake loss-modeling arena (including USGS PAGER developers), have specifically requested additional ShakeMap archiving. As such, the USGS now employs a fully documented database of ShakeMap products and metadata. ShakeMaps, like other NRT earthquake information products, are now stored in the Comprehensive Catalogue (ComCat) database as part of broader USGS Web enhancements [24]. Unlike the earlier generation of ShakeMaps, which only provided access to the latest revisions, users will be able to access all prior versions and from each authoritative ShakeMap contributing network via web and product distribution feeds [17]. It is anticipated that the better documentation and organization of these ShakeMap collections within databases will facilitate Cat model testing and validation, among other uses.

Along with the new documentation, revised ShakeMap Disclaimers address policy concerning ShakeMap revisions and finality (http://usgs.github.io/shakemap/disclaimers), albeit perhaps not to everyone's liking. In essence, despite the desire for a scenario and NRT ShakeMap and other products to become static after some fixed period of time, USGS can and does routinely update ShakeMap as new constraints, data, or algorithms warrant, and the USGS reserves the right to update or correct maps as scientifically or operationally necessary. Critically, however, all such updates are now well documented [17], and prior versions will be archived.

4. Conclusions

Although difficult to quantify precisely, several billions of dollars of relief and recovery funds are at stake immediately after damaging earthquakes around the globe. This study describes the various financial instruments currently in place alongside the parallel advances taking place in the scientific community, and in particular within the USGS, to furnish the NRT hazard information on which they rely.

The partially proprietary nature of Cat models and other financial instruments can hinder the iterative process of scientific research and development. When such interactions do take place, progressively better understanding of the tools of the trade and specific needs of the financial sector may further enhance NRT earthquake information systems, which in turn may enhance the further development of financial instruments.

As technical capabilities advance, the consistency among past, present, and future hazard models supports innovation in loss modeling and thus opens new avenues in financial decision-making in the industry as well as within scientific groups like the USGS and the Global Earthquake Model (GEM) consortium. It is anticipated that increasing transparency and documentation, refining metadata, and enhancing the format and performance of NRT products will help facilitate development and further uptake of creative products in the financial sector as part of the larger process of distributing risk for the benefit of society.

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6. References

[1] Grossi P (2005): Catastrophe modeling: a new approach to managing risk. Springer Science & Business Media.

[2] Franco G (2015): Earthquake Mitigation Strategies Through Insurance. In Beer M, Kougioumtzoglou IA, Patelli E, Au IS-K (eds). *Encyclopedia of Earthquake Engineering*, Berlin, Heidelberg: Springer Berlin Heidelberg. 1–18. Retrieved November 10, 2015, from http://link.springer.com/10.1007/978-3-642-36197-5_401-1

[3] Given DD, Cochran ES, Heaton T, Hauksson E, Allen R, Hellweg P, Vidale J, Bodin P (2014): Technical implementation plan for the ShakeAlert production system: An earthquake early warning system for the West Coast of the United States. US Geological Survey.

[4] Iervolino I, Chioccarelli E, Giorgio M, Marzocchi W, Zuccaro G, Dolce M, Manfredi G (2015): Operational (short-term) earthquake loss forecasting in Italy. *Bull. Seismol. Soc. Am.*

[5] Wald DJ, Jaiswal K, Marano K, Bausch D (2009): Developing casualty and impact alert protocols based on the USGS Prompt Assessment of Global Earthquakes for Response (PAGER) system. In *Second International Workshop on Disaster*, pp.15–16. Retrieved October 9, 2013, from http://ehp3-earthquake.wr.usgs.gov/earthquakes/pager/prodandref/Wald_David2.pdf

[6] Wald D, Lin K-W, Porter K, Turner L (2008): ShakeCast: Automating and Improving the Use of ShakeMap for Post-Earthquake Decision-Making and Response. *Earthq. Spectra*, **24**(2), 533–553.

[7] Artemis (2016): Catastrophe bonds, insurance linked securities, reinsurance capital & investment, risk transfer intelligence. Retrieved May 11, 2016, from www.artemis.com

[8] Acton C (2015): Financial Sector. ATC/USGS Seismic Hazard User-Needs Workshop, September, 2015, Menlo Park, CA. Retrieved May 11, 2016, from https://www.atcouncil.org

[9] Franco G (2013): Construction of customized payment tables for cat-in-a-box earthquake triggers as a basis risk reduction device. In Safety, reliability, risk and life-cycle performance of structures and infrastructures: proceedings of the 11th International Conference on Structural Safety and Reliability, New York, USA, 16-20 June 2013. Boca Raton, Fla.: CRC Press.

[10] Franco G (2010): Minimization of Trigger Error in Cat-in-a-Box Parametric Earthquake Catastrophe Bonds with an Application to Costa Rica. *Earthq. Spectra*, **26**(4), 983–998.

[11] Ramirez C (2015): USGS and AIR Worldwide: Leveraging Seismic Hazard as an Ingredient in Risk Modeling. ATC/USGS Seismic Hazard User-Needs Workshop, September, 2015, Menlo Park, CA, Retrieved May 11, 2016, from https://www.atcouncil.org

[12] CoreLogic (2012): Modeling Earthquake Risk Whitepaper. Retrieved February 22, 2016, from http://www.corelogic.com/about-us/researchtrends/modeling-earthquake-risk-white-paper.aspx

[13] CelciusPro Nat Cat and weather products. Nat Cat and Weather products. Retrieved May 11, 2016, from http://www.celsiuspro.com

[14] ReliefWeb (2016): IDB supports Ecuador with credit line of $300 million after the earthquake. Retrieved May 11, 2016, from http://reliefweb.int/report/ecuador/idb-supports-ecuador-credit-line-300-million-after-earthquake

[15] Engineering C of U for R in E, Osteraas J (2007): General Guidelines for the Assessment and Repair of Earthquake Damage in Residential Woodframe Buildings. Consortium of Universities for Research in Earthquake Engineering.

[16] Wald DJ, Worden BC, Quitoriano V, Pankow KL (2005): ShakeMap® Manual: Technical Manual, users guide, and software guide Version. **12-A1**, 132.

[17] Worden CB, Wald DJ ShakeMap Manual. Retrieved May 10, 2016, from http://usgs.github.io/shakemap/

[18] Worden CB, Wald DJ, Hearne MG, Pagani M Complimentary Components of OpenQuake and ShakeMap M. Hearne (USGS), D. J. Wald (USGS), M. Pagani (GEM Foundation). *Proc 16WCEE Santiago*, 2017.

[19] Allen TI, Wald DJ, Earle PS, Marano KD, Hotovec AJ, Lin K, Hearne MG (2009): An Atlas of ShakeMaps and population exposure catalog for earthquake loss modeling. *Bull. Earthq. Eng.*, **7**(3), 701–718.

[20] Bozorgnia Y, Abrahamson NA, Atik LA, Ancheta TD, Atkinson GM, Baker JW, Baltay A, Boore DM, Campbell KW, Chiou BS-J, others (2014): NGA-West2 research project. *Earthq. Spectra,* **30**(3), 973–987.

[21] Thompson EM, Wald DJ, Worden CB (2016): A Strategy for Generating Systematic USGS Earthquake Scenarios. US Geological Survey.

[22] Park J, Bazzurro P, Baker JW (2007): Modeling spatial correlation of ground motion intensity measures for regional seismic hazard and portfolio loss estimation. *Appl. Stat. Probab. Civ. Eng. Taylor Francis Group Lond.*, 1–8.

[23] Verros S, Wald DJ, Ganesh M, Worden CB, Hearne MG, Horspool N (2016): Computing Spatial Correlation of Ground Motion Intensities for ShakeMap, April 2016. Reno, Nevada. p.

[24] Guy MR, Patton JM, Fee J, Hearne M, Martinez E, Ketchum D, Worden C, Quitoriano V, Hunter E, Smoczyk G, Schwarz S (2015): National Earthquake Information Center systems overview and integration. Reston, VA. Report 2015–1120.