IMPACT OF TIME DEPENDENT RECURRENCE MODELING ON SEISMIC RISK ASSESSMENT: CALIFORNIA CASE STUDY

C.R. Williams[1], H. Aslani[2], G. Molas[3], P. Seneviratna [4], and D.S. Windeler[5]

[1] *Senior Project Director, Model Development, Risk Management Solutions, Inc., Newark, California, USA*
[2] *Lead CAT Risk Modeler, Model Development, Risk Management Solutions, Inc., Newark, California, USA*
[3] *Senior Director, Model Development, Risk Management Solutions, Inc., Newark, California, USA*
[4] *Lead CAT Risk Modeler, Model Development, Risk Management Solutions, Inc., Newark, California, USA*
[5] *Director, Model Management, Risk Management Solutions, Inc., Newark, California, USA*

Email: Chesley.Williams@RMS.com, Hesaam.Aslani@RMS.com, Gilbert.Molas@RMS.com, Pasan.Seneviratna@RMS.com, and Donald.Windeler@RMS.com

ABSTRACT:

Seismic risk assessments are based on a combination of seismic hazard, building vulnerability and exposure characteristics. This analysis examines how key assumptions within the seismic hazard component mainly the recurrence modeling can impact seismic risk. This study compares the risk results for California for an economic portfolio of single-family residential structures produced for a time-independent recurrence model and a model including time-dependent recurrence for key fault systems. The resulting analysis shows on a California wide portfolio that the annualized losses are impacted by >5% for residential structures when comparing short-term to long-term event rates. However, not surprisingly, there are very large localized increases (up to +45%) in regions where events are overdue (e.g., along the Hayward-Rodgers Creek System) and decreases where events have recently happened (e.g., along the San Andreas fault system that ruptured in 1906). This analysis give credence to the need for the inclusion in seismic risk assessments of time dependent recurrence particularly for insurance contracts which typically have short duration (e.g., 1-year).

KEYWORDS: Seismic Hazard, California, Time-Dependent Recurrence, Residential Exposure

1. INTRODUCTION

A seismic risk model has been developed for California for use by the insurance/reinsurance industry to assess and to manage earthquake risk to exposures. California's high seismicity is dominated by the oblique collision of the North America and Pacific Plates. Major fault systems have developed across this plate boundary to accommodate the majority to the plate motion. This study examines the key underlying assumptions about the recurrence on the most active structures within this boundary. These "A-Type" faults have the highest slip rates and highest characteristic magnitudes and as a result dominate the risk for the region. When modeling the recurrence on such structures a key assumptions is whether to model their recurrence as a purely poisson process (time independent) or to use time-dependent recurrence that include information about the timing of the last event to adjust the recurrence for the next event.

Time dependent recurrence modeling is based on the concept of an earthquake cycle. The earthquake cycle is based on the "elastic rebound theory" first proposed by H.F. Reid following the 1906 Great San Francisco Earthquake [Reid (1910)]. Through his observations of the ground deformation from the 1906 earthquake and previous events, Reid proposed the earthquakes are the release of elastic energy that has slowly accumulated over a long period. This means that with information about the timing of the last event and knowledge of the average interval between several past events that it is possible to assess the short-term likelihood of an event on a fault. In other words, if an event is has just happened another event is unlikely until enough stress has been accumulated. Conversely, if an event has not happened for a significant period of time compared to the average recurrence interval, then the next event may be more likely to occur. From an insurance perspective, the possibility of temporal variations in risk is important as contracts are typically written to cover risk on an annual basis.

To examine the impact of time dependent (or short-term event rates), this study compares two recent studies completed by the United States Geological Survey (U.S.G.S.). In early 2008, the U.S.G.S. released an updated version of the National Seismic Hazard Maps for the United States [Petersen et al. (2008)]. For California, the underlying seismic source model developed by the 2007 Working Group of California Earthquake Probabilities (2007 W.G.C.E.P.) and assumes that all events were time independent. Additionally, in early 2008, the 2007 W.G.C.E.P. developed a model that included time-dependent recurrence for those A-Type faults with detailed event chronologies such as the San Andreas Fault System, the Hayward-Rodgers Creek Fault System and the San Jacinto Fault System [2007 W.G.C.E.P. (2008)]. The two underlying seismic source models are identical except for the underlying recurrence modeling assumptions for the key A-Type faults and are the basis for this analysis.

2. METHOD

The method used to examine the impact of time-dependent recurrence assumptions in California was to based on a seismic risk model in conjunction with an exposure database representing the distribution and value of the single family residential building value and contents. This exposure was then analyzed using two alternate set of events rates: a time-independent (long-term) and time-dependent for key structures (short-term).

2.1. Risk Framework

Results provided in this study were calculated using a proprietary loss-estimation tool called RiskLink. It applies an event-based approach (using a set of stochastic events with corresponding physical parameters, location, and frequency of occurrence) to generate portfolio loss and to assist in risk management.

The RiskLink seismic risk model has four principal components or modules:

1. <u>Stochastic Event Module</u>: This module contains a database of stochastic earthquake events. Each event is described by its physical parameters, location, and frequency of occurrence.
2. <u>Hazard Module</u>: This module determines the earthquake induced ground shaking at each property location for every stochastic earthquake event and examines ground motion relationships and adjustments for site conditions (soil amplifications and liquefaction and landslide susceptibilities). Ground motions are calculated in spectral acceleration from periods 0 to 4 seconds. The ground motion for an individual location also incorporates the building's predominant period.
3. <u>Vulnerability Module</u>: This module calculates the mean damage ratio and coefficient of variation to buildings, contents, and the resulting loss of use.
4. <u>Financial Analysis Module</u>: This module calculates losses to different financial perspectives and structures, considering the insurance and reinsurance financial structures.

For this analysis, the RiskLink tool was used to analyze the single family residential exposure and to determine annualized as well as return period loss levels. In addition to looking at California state-wide perspectives, the tool was also used to compare losses to exposures in the San Francisco Bay Area and the Los Angeles regions.

2.2. Single Family Residential Exposure

This economic exposure incorporates coverages for structures, contents, and additional living expenses. These were estimated from a value of public and private data sources, including insurance companies, state insurance regulators, the California Earthquake Authority, the U.S. Census, gross domestic product, Dun & Bradstreet square footage, Means construction costs, and other statistical factors. In addition to this information, detailed inventory data is used to distinguish construction classes for residential structures. In California, the single-family residential building stock is predominantly wood frame.

Figure 1 shows the spatial distribution of the single-family residential exposure across California as well as in the population concentrations around San Francisco and Los Angeles. For the San Francisco Bay Area, nine counties are analyzed: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma. For the Los Angeles region, four counties are used: Los Angeles, Orange, Riverside and Ventura. These counties are highlighted with bold outlines in the regional images included in Figure 1.

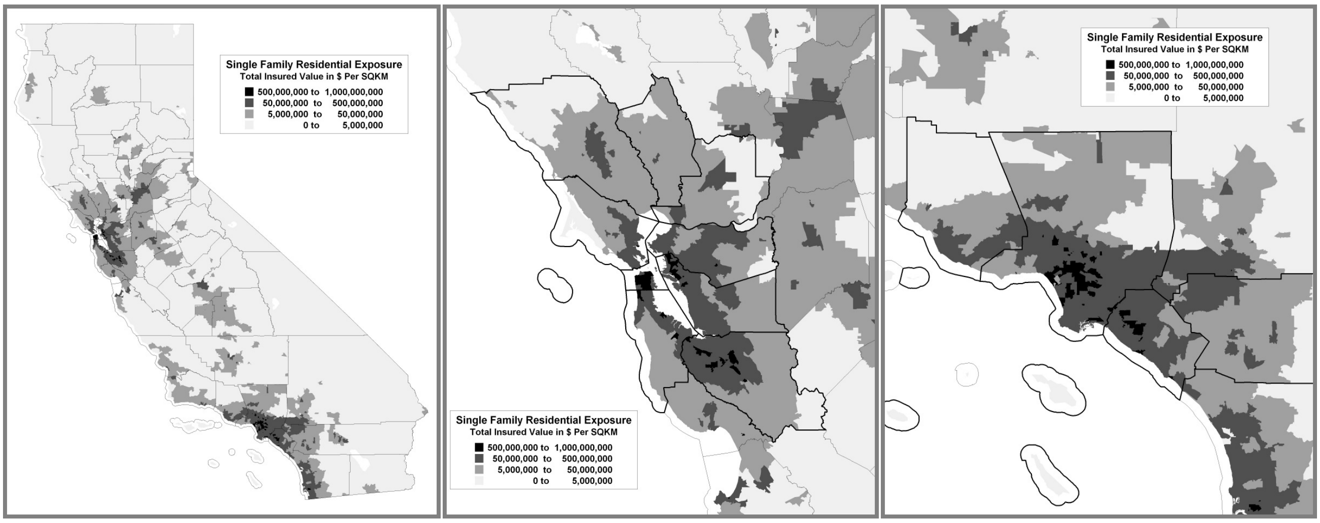

Figure 1 Single family residential exposure by postal code by value per square kilometer.

The goal of this analysis was to examine the sensitivities around rate assumptions, so the results that are presented are normalized by exposure into loss ratios. For this reason, the details behind the exposure values are not critical for this analysis and are not explained more fully here.

1.2. Long-Term Event Rates (Time Independent)

The basis for the long-term (time independent) event rates is the work done by the 2007 W.G.C.E.P. that was incorporated in the 2008 U.S.G.S. National Seismic Hazard Maps [Petersen et al. (2008)]. These maps are mandated to represent the “best available science” and were updated in 2008 to incorporate new science in ground motions modeling and fault characterization as well as new ground deformation and seismicity rate observations. The National Maps were developed to be applied in the seismic provisions of the building codes. For this reason, a time independent perspective on event recurrence is used, because building requirements need to temporally consistent. An important validation of the underlying source model and event rates for the National Maps is a comparison of the modeled to observed historical event rates. This means that the model represents on long-term (or time independent) perspective on event rates.

Note that the underlying seismic source model and ground motion models used in the RiskLink analysis are consistent with those used in the National Maps.

1.1. Short-Term Event Rates (5-Year Time Dependent)

In addition to building a model for the National Seismic Hazard Maps, the 2007 W.G.C.E.P. was also commissioned to develop a California statewide seismic source model that incorporated time dependent recurrence modeling for key faults [2007 W.G.C.E.P. (2008)]. This research is the source for the short-term (time dependent) event rates for key structures. These key structures or A-Type faults [shown in Figure 2] have the highest slip rates and highest characteristic magnitudes and as a result dominate the risk in California. Note that the rates calculated by the 2007 W.G.C.E.P. were primarily focused on 30-year time window annual event rates. For this analysis, their 5-year time-window annual event rates were used.

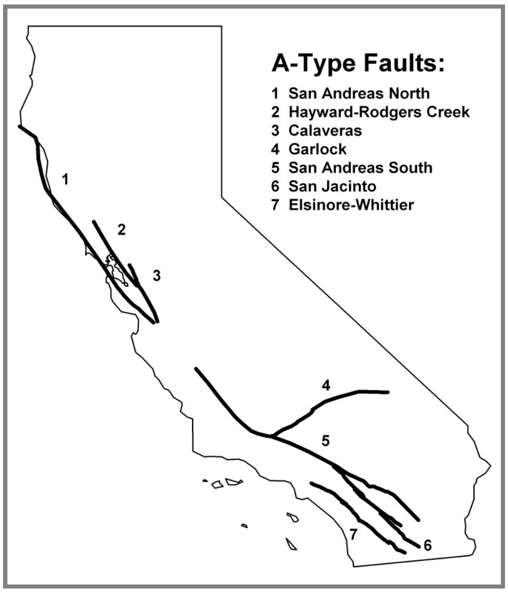

Figure 2 A-type faults with time dependent recurrence modeling in this study.

3. RESULTS

Three sets of analysis results were derived for this study: return period loss ratios, average annual loss (AAL) ratio and postal code level loss costs. The return period loss ratios are derived from the loss-exceedance curve. The loss-exceedance curve is derived from the full suite of seismic events that could impact the economic exposure. The loss-exceedance curve plots the probability of exceeding a particular loss level in a year. Many insurers prefer to think of losses in terms of “return periods”, usually treated as the simple inverse of the corresponding probability from the loss-exceedance curve. Loss-exceedance curves provide insurers with the quantification needed to assess solvency issues and manage their portfolios. Average annual losses (AAL) are calculated by summing the product of the expected loss level and the annual rate for all possible events affecting the exposure. By annualizing the expected losses due to events of varying severities and recurrence intervals, annual premium rates can be set with longer term risk planning in mind.

The resulting analysis [Figure 3] shows on a California wide portfolio that the annualized losses are impacted by >5% for residential structures when comparing short-term to long-term event rates. The return period losses are more impacted at the shorter return periods than the longer. The regional results for San Francisco and Los Angeles show similar with the San Francisco Bay region seeing slightly higher impacts.

To better understand the spatial distribution of the changes, postal code level annual average loss values were determined and then normalized by exposure to produce loss cost values per $1000 of exposure. Plots of these values for the two rates sets are included in Figure 4 along with maps showing the regions that experience increases in loss costs as well as the distribution of decreasing loss costs. Not surprisingly, there are very large localized increases (up to +45%) in regions where events are overdue along the Hayward-Rodgers Creek and the Southern San Andreas Fault systems. The observed decreases are mainly driven by the lower rates on the Northern San Andreas due to the fact that there was a historical event in 1906 on this structure. This Northern San Andreas effect is seen more distant from the San Francisco Bay area because the immediate loss costs are increasing due to overdue events on structures in the east bay (Hayward and Calaveras fault systems). The Northern San Andreas produces significantly larger events in the lower magnitude eight range as compared with the other systems in the region which can only produce mid-range sevens. This means the Northern San Andreas has a larger footprint of influence as seem in the Northern California.

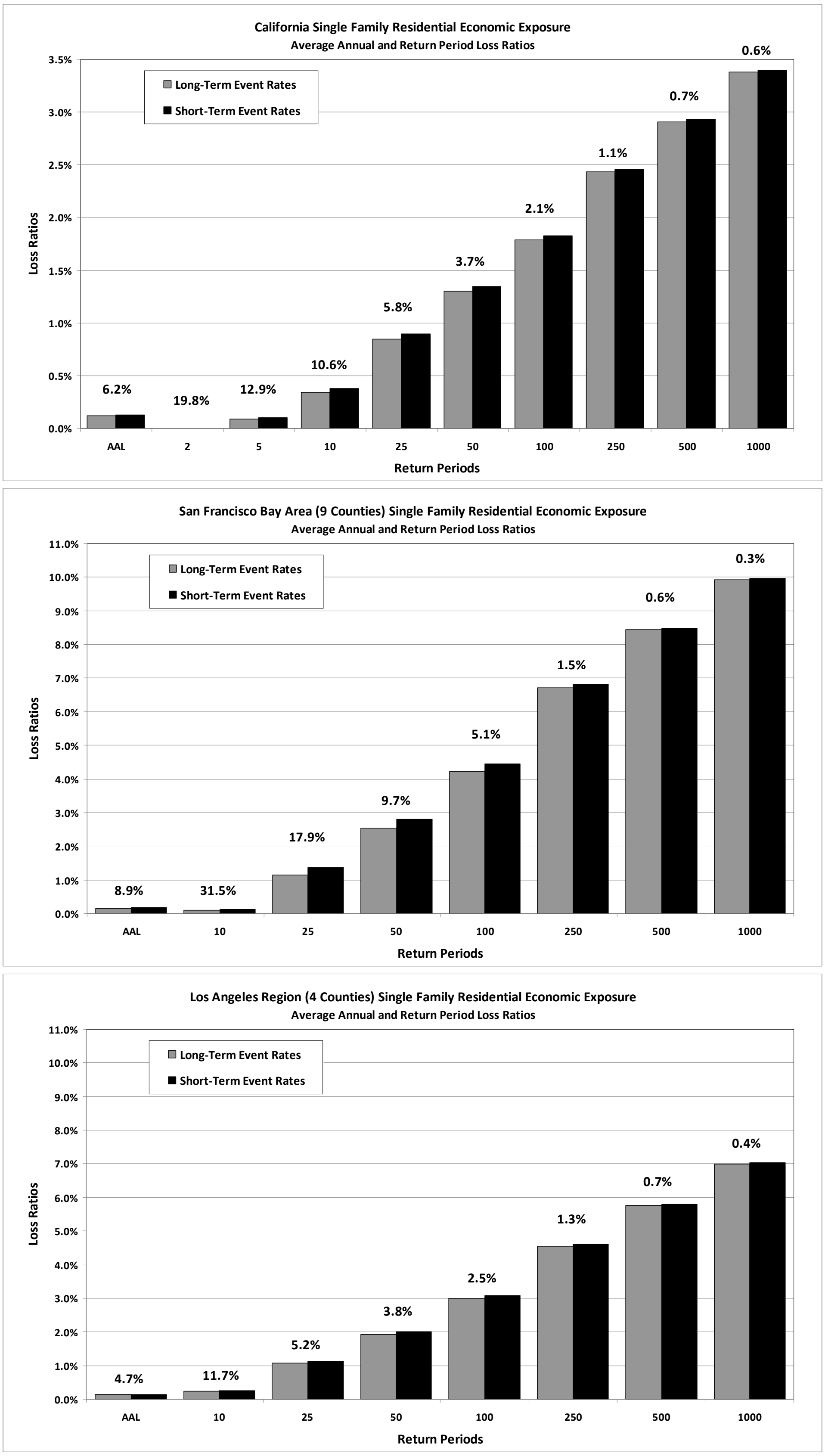

Figure 3 Average annualized (AAL) and return period loss ratio comparison for long-term and short-term event rates: California state-wide, San Francisco and Los Angeles region.

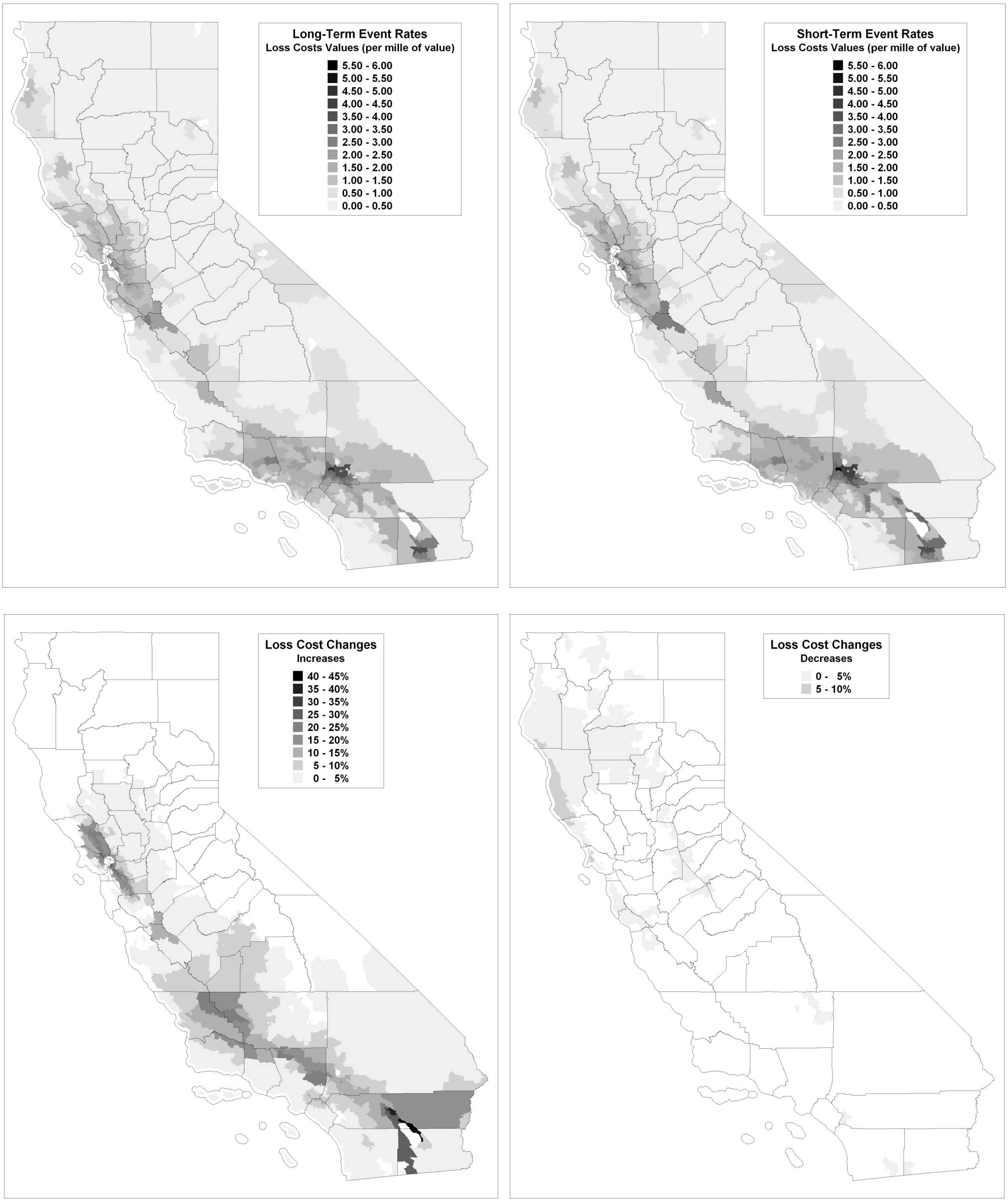

Figure 4 Loss cost value maps comparing long-term (top left) and short-term rates (top right).
Bottom left: increases in loss costs due to inclusion of time dependent rates.
Bottom right: decreases in loss costs due to inclusion of time dependent rates.

4. CONCLUSIONS

This paper examines the impact of time dependent recurrence on seismic risk results for the state of California. The impact of time dependent recurrence on hazard results using earlier versions of the source and event rate models used here was previously published by Petersen et al. (2007). Similar to Petersen et al. (2007), the risk perspective shows little changes to risk to locations distant from the sources modeled with time dependent recurrence. The risk perspective is focused on the concentrations of exposures in the San Francisco and Los Angeles metro-regions. These two regions are impacted by the A-Type faults and therefore see significant differences comparing the impact of the event rates. This study give credence to the need for the inclusion in seismic risk assessments of time dependent recurrence particularly for insurance contracts which typically have short duration (e.g., 1-year).

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REFERENCES:

2007 Working Group on California Earthquake Probabilities. (2008). The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2): U.S. Geological Survey Open-File Report 2007-1437 and California Geological Survey Special Report 203.

Petersen, M.D., Cao, T., Campbell, K.W., and Frankel, A.D. (2007). Time-independent and Time-dependent Seismic Hazard Assessment for the State of California: Uniform California Earthquake Rupture Forecast Model 1.0, Seismological Research Letters Volume 78, Number 1, pp. 99-109.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Y., Boyd, O.S., Perkins, D.M., Luco, N., Field, E.H., Wills, C.J., and Rukstales, K.S. (2008). Documentation for the 2008 Update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008–1128, 61 p.

Reid, H.F. (1910). The mechanics of the earthquake, v. II of Lawson, A.C., chairman, The California earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission: Carnegie Institution of Washington Publication 87, 192p. (reprinted in 1969).