A new evaluation of Seismic Hazard for the Central America Region in the frame of the RESIS II Project.

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ABSTRACT

A new evaluation of seismic hazard in the Central America region has been carried out, in the frame of the cooperation project RESIS II, financed by the Norway Cooperation Agency (NORAD). Different experts in seismic hazard from Costa Rica, Guatemala, Nicaragua , El Salvador, Norway and Spain participated in the study, which was aimed at obtaining results suitable for seismic design purposes. The analysis started with an exhaustive revision of the seismic catalogues of each country from which a global catalogue for CA has been configured and homogenised at moment magnitude, Mw. Seismotectonic models proposed for the region were revised and a regional zonation was proposed, taking into account seismotectonic data, seismicity, focal mechanisms, GPS observations and other evidences useful for defining seismic sources. In parallel, attenuation models for subduction and volcanic crustal zones were revised and the more suitable models were calibrated with strong motion data. Taking the previous inputs, the seismic hazard analysis was developed in terms of peak ground acceleration, PGA and spectral accelerations SA (T) for periods of 0.1, 0.5, 1 and 2 s, through the PSHA methodology (Probabilistic Seismic Hazard Assessment). As a result, different hazard maps were obtained for the quoted parameters, together with Uniform Hazard Spectra (UHS) in the main populations of Central America. This is the first study developed at regional scale after the last earthquakes that have occurred in the region and as a result the new generation of maps will be useful in the revision of seismic codes of the area.

1. INTRODUCTION

Firts studies of seismic Hazard in Centralamerica were carried out after the Managua 12972 and Guatemala 1976 earthquakes, at a national scale by the laboratory of John Blume Earthquake Engineering Center, Stanford University (California). At a regional level, different studies were developed between 1990 and 2000 (Rojas et al, 1993a y b; GSAHP, Shedlock, 1999). Most part of these studies were enforced by the International Decade for Reduction of Natural Disasters ", promoved by United Nations. In this frame, the Project RESIS I was financed by the Norway Cooperation Agency (NORAD) and the Centro de Coordinación para la Reducción de Desastres en América Central, (CEPREDENAC), aimed at the evaluation of the seismic hazard for Central America. As main results its worthy to note a Strong Motion Data Base (Taylor et al., 1992), some spectral attenuation models (Climent et al.,1994; Dahle et al., 1995; Schmidt et al., 1997), a seismic catalogue (Rojas et al., 1993), empirical relationships for homogeneization to moment magnitude Mw (Rojas et al, 1993b), the creation of the Centro Sismológico de América Central, CASC, and seismic hazard maps for the countries of the region.

A new generation of seismic hazard maps, with specific results in the capitals have been obtained in a frame of a new project, RESIS II, which is a continuity of the previous one, also financed by NORAD and CEPREDENAC. The study has been carried out for seismologist of all the countries of Central America who worked together in a workshop celebrated in the Universidad Politécnica de Madrid in April, 2008. Decisions about questions related to seismic hazard evaluation , such as seismic catalogue, seismogenic zonation, selection of ground motion models, etc, have been taken with the consensus of all of them. A summary of the study and the mains results is presented here.

2. SISMOTECTONIC FRAME

Central America is located in the western limit of the Cocos plate. This plate is surrounded by the North American, Caribbean, Nazca and South American plates. The Cocos-Caribbean contact is convergent or of subduction. Nazca and Caribbean plates are limited by the Southern Panama Deformed Belt (SPDB). The transcurrent faults of Polochic-Motagua-Chamelecón (PMCHF), Panama Fracture Zone (PFZ), and the Atrato Suture Zone (ASZ) form the limits of the North American-Caribbean plates, Cocos-Nazca plates and Caribbean-South America plates, respectively (figure 1). Other important tectonic units are: the Hess Scarp, Nicaragua Depression and the southern Panama Fault Zone. Recently, it has been proposed that the southern half of Costa Rica, Panama and Northwest Colombia constitute an individual microplate named Panama microplate. In this region, relative plate motions vary between 2 and 9 cm/year are accompanied by active volcanism and high shallow and intermediate seismicity

Three seismic scenarios may be distinguished in the region: The subduction zone, in the plate boundary Cocos-Caribe; the local faults located in the volcanic chain and the limit North America- Caribe. Many destructive earthquakes occurred in the last 500 years with high or moderate magnitudes, associated to the three scenarious. Figure 1 shows the tectonic map of the region.

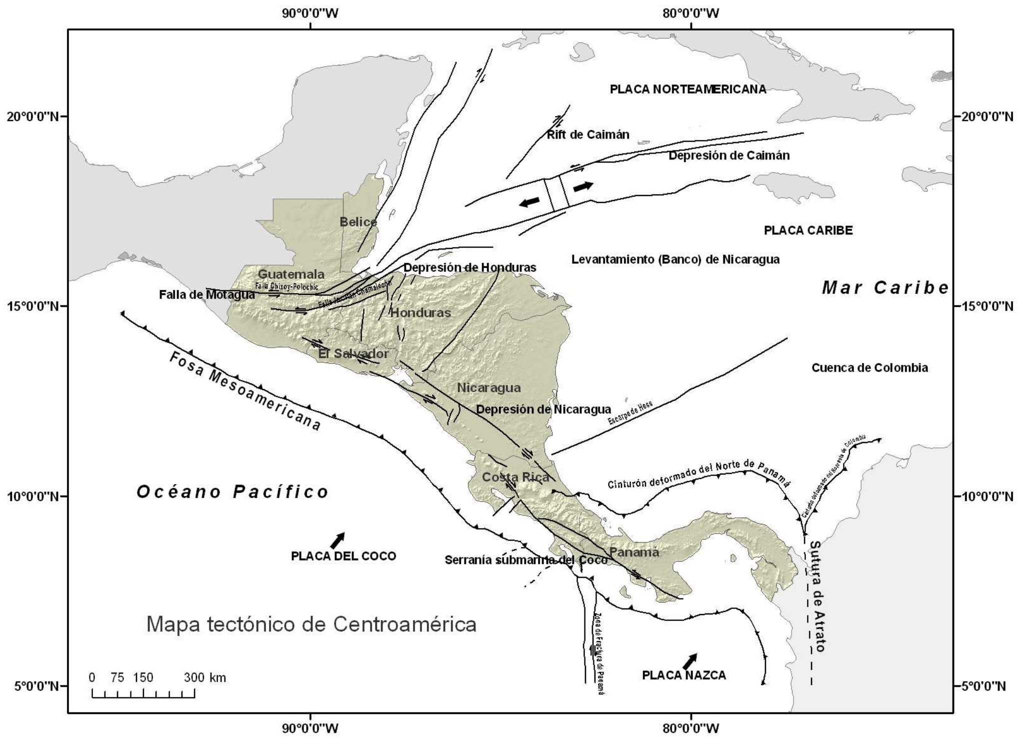


Figure 1. *Tectonic Map of Central America (Alvarado, personal communication)*

Many destructive earthquakes took place in the region, most of them with moderate magnitude (Mw ~ 6.5) located in the system faults around the volcanic chain, surface focus and epicenter close to the population centers. In the last decades the more destructive event was the ones associated to the Motagua fault, Mw 7.6, causing 22.000 died in Guatemala City. In 1972 other strong earthquake, Mw 6.2, caused more than 10.000 died people in Managua. Other earthquakes occurred in the subduction zone with highest magnitudes, Mw> 7.5, but minor damages due to their major focal depth and epicentral distance to the population centers, as the one on Jannuary, 2001 in El Salvador.
Figure 2 shows the maps with the focal mechanism of the events with magnitudes M_w bigger than 6.0, occurred since 1976 (Global CMT, 2008) in the main tectonic structures of the region.

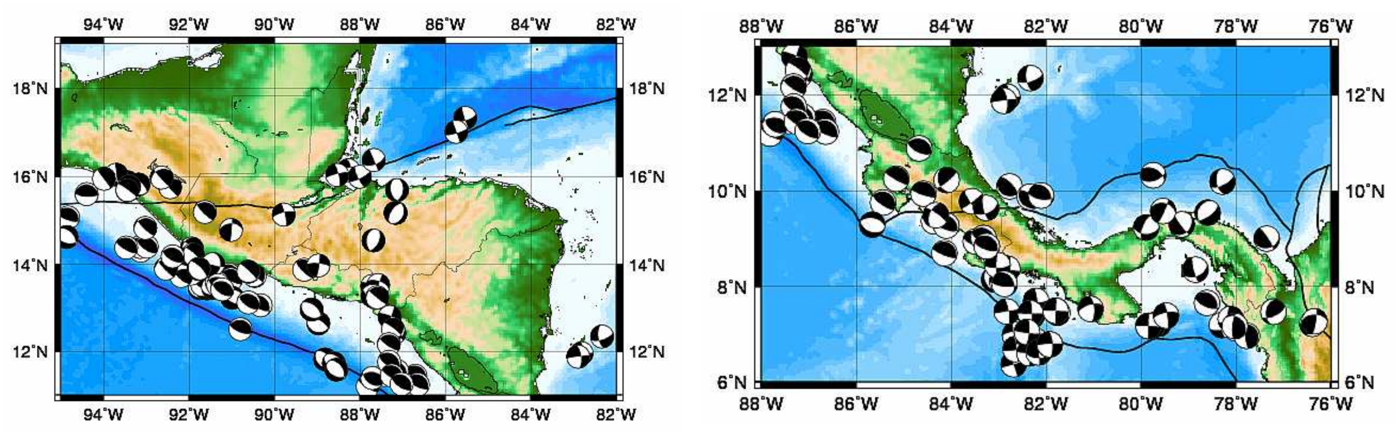


Figure 2. Focal mechanism of the events with magnitudes M_w > 6.0, occurred since 1976 (Global CMT, 2008) in Central America. Left: Septentrional CA; right: Meridional CA

3. SEISMIC HAZARD APPROACH (ROCK SITES)

The seismic hazard analysis will follow a probabilistic zoning method according to the well known PSHA methodology. A logic tree with a node for capturing epistemic uncertainty related ground-motion models is formulated. In a first phase, the inputs for the application of this method have been prepared: Seismic catalogue, seismogenic models and attenuation laws.

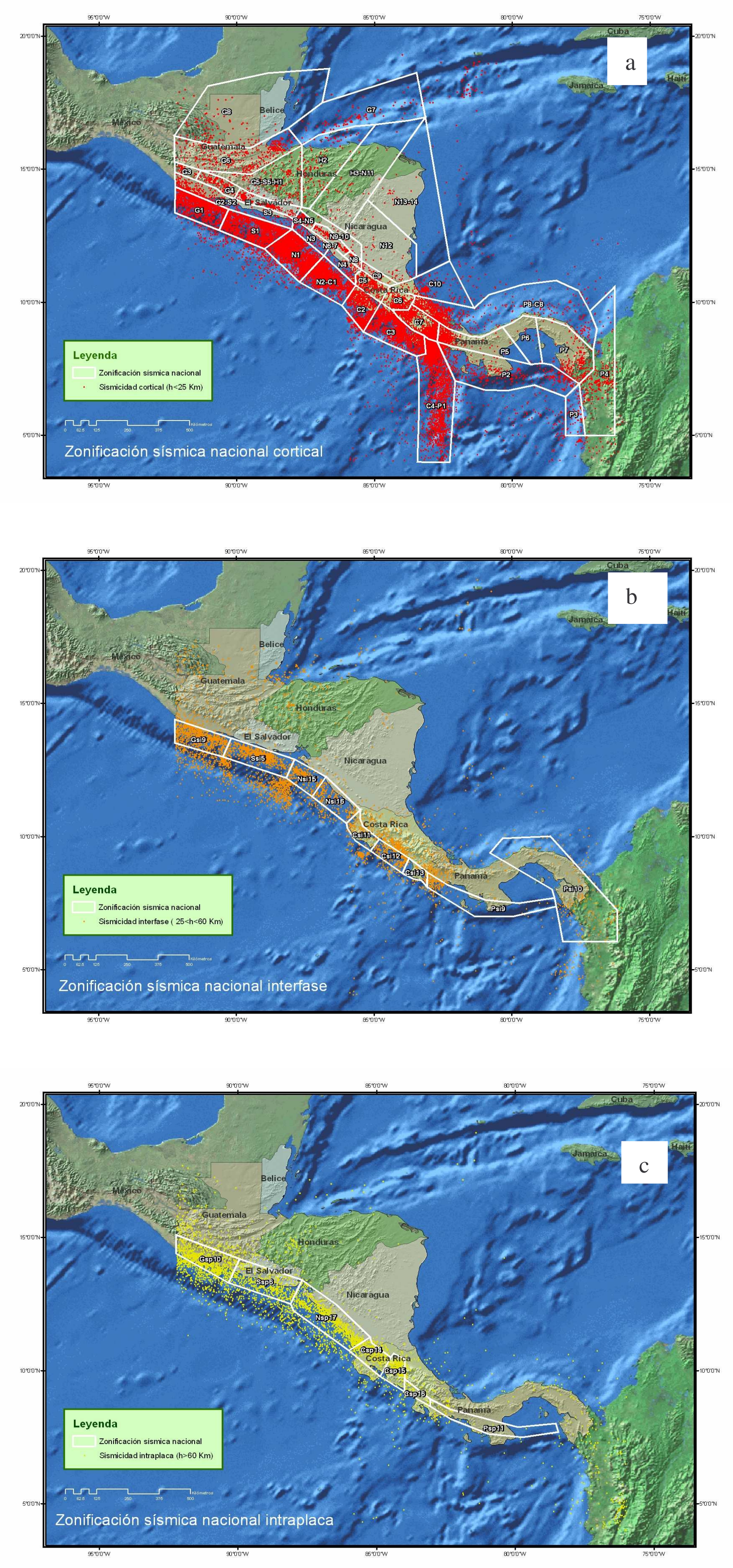
3.1. Seismic Catalogue

A regional catalogue has been created updated at 2007, starting on the Rojas et al (1993a) catalogue, with data of the Centro Sismológico para América Central (CASC) and the national catalogues of El Salvador ,Nicaragua, Costa Rica y Panamá. A careful revision has been carried out in order to avoid duplicity of events especially in the boundaries of the different countries. The catalogue in SEISAN format includes macroseismic events reported since 1522 and instrumental shocks recorded in the last decades. The size parameter has been homogenized to Mw, using relationships derived for the different countries. After the revision, depuration and homogenization, the regional catalogue is configured by 29.918 events with Mw> 3.5.

3.2 Seismogenetic zones and seismic parameters

A seismogenic zonation has been proposed, combining tectonic and seismic criteria. This contains three groups of zones: crustal, subduction interface and subduction inslab. The zones are defined at national detail, but they are coherent at a regional scale avoiding discontinuities in the boundary of the countries. Morever, the adopted zoning joints the agreement of the specialist of the different countries in the region.

In order to estimate the recurrence models of the zones, the seismicity has been associated as follows: surface seismicity (h< 25 km) to crustal zones; intermediate seismicity (25 km< h< 60 km) to interface zones and deep seismicity (h> 60 km). Figure 3 show the three groups of zones superpose to their respective seismicity.



The seismicity of each zone is fit to a Gutenbrg-Richter model truncated to a minimum magnitude m_0 =4.5. Therefore we estimate the annual rate of events with $m \geq m_0$ [$N(m_0)$] and the scope of the G-R law (b o β) for characterizing the recurrence. A Gussian normalized distribution is considered for the maximum magnitude, taking into account the maximum historical earthquake and maximum potential shock based in the tectonic criteria.

The variation range for the b values obtained are coherent with the typical values according the tectonic regime found in other places : [1.0-1.3] in prearc zones , with extensional regime; [0.8-1.3] in transarc zones and deformed belts with inverse fault; [0.7-0.9] in volcanic chain with distensive regime, [0.6-1.1] in interfase and inslab plate.

Figure 3. *Sismogenic zones adopted for the seismic hazard assessment.*

a. *Crustal zones superposed to surface seismicity*
b. *Interfase zones superposed to intermediate seismicity*
c. *Inslab zones superposed to deep seismicity*

3.3 Selection of ground motion models

We developed an exhaustive study aimed at choosing the more suitable strong-motion models for seismic hazard analysis in the Central America Region. After a careful revision of the state of the art, different models developed for subduction and volcanic crustal zones, in tectonic environment similar to those of CA, were selected. These models were calibrated with accelerograms reordered in Costa Rica, Nicaragua and El Salvador. The peak ground acceleration PGA and Spectral Acceleration SA (T) derived from the records were compared with the ones predicted by the models in similar conditions of magnitude, distance and soil. The type of magnitude (M_s, M_b, M_w), distance (R_{hyp}, R_{rup}, etc) and ground motion parameter (maximum horizontal component, medium, etc) was taken into account in the comparison with the real data. As results of the analysis, the models which present a best fit with the local data were identified: Climent *et al.* (1994) for crustal zones, Youngs *et al.* (1997) for subduction interface and insalb and Zhao *et al.* (2006) for crustal and inslab zones (Herefore these models are named CLI94, YOUN97 and ZH06). The study done for calibration of the models is presented in detail in the paper xxxxx (Climent et al, 2008).

3.4. Seismic Hazard estimation and results

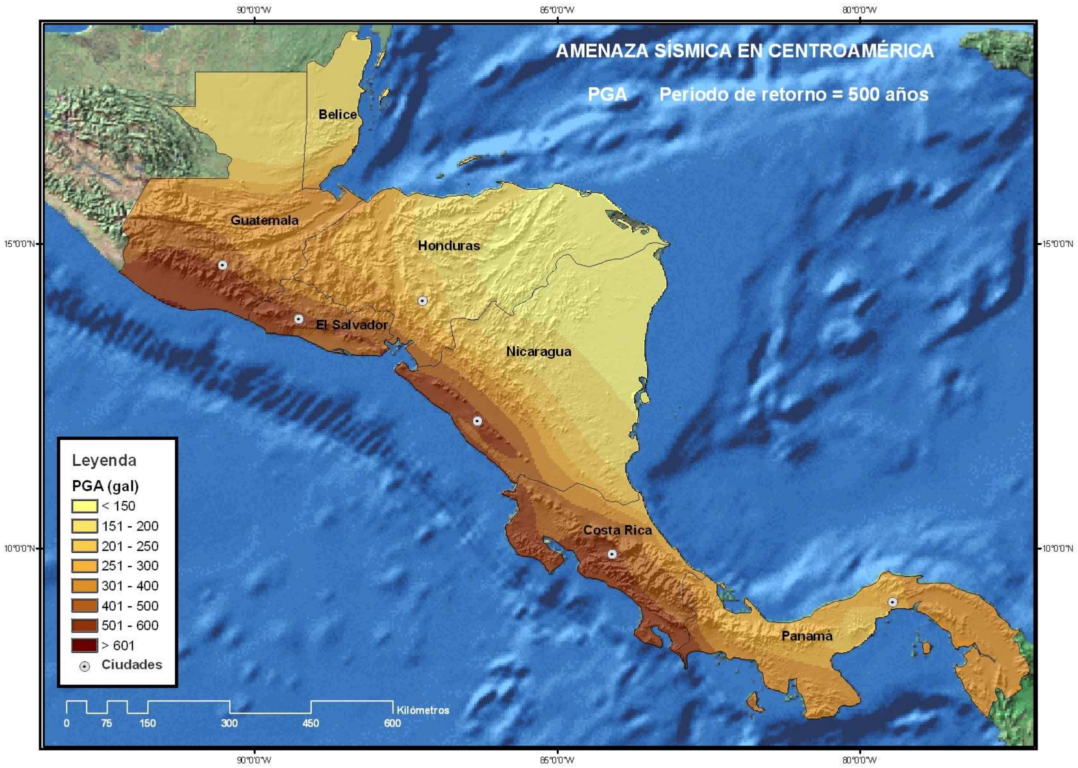
With the previous inputs the hazard has been estimated through the CRISIS 07 program (Ordaz *et al.*, 2007) in points of a grid covering all the Central America region, equiespazed 0.1 º in latitude and longitude, in terms of peak ground acceleration PGA and spectral accelerations SA (T) for T= 0.1, 0.2, 0.5, 1 y 2 s and for return period RP = 500, 1000 and 2500 years. Four combination of the chosen ground motion models (each combination mix models for crustal, interface and inslab zones) have been taken for the hazard estimates, configuring 4 branches in the logic tree: 1) CLI94+YOUN97+YOUN97; 2) CLI94+YOUN97+ZH06; 3) ZH06+YOUN97+YOUN97 and 4) ZH06+YOUN97+ZH06. All the combinations are considered with the same weight (0.25) in the logic tree.

We represent maps for PGA , SA (0.2s) and SA (1s) and for the three return period, obtaining a total of 9 maps which reflect the seismic hazard for the entire region on rock conditions. These maps represent mean values obtained with the four combinations of the attenuation models. As example of the results, Figure 4 show the maps of PGA and SA (1 S) for RP= 500 years.

In addition, we obtain hazard result specific for the 6 capitals of the Central America countries: Guatemala City, San Salvador, Managua, Tegucigalpa, San José y Panamá. In these towns we draw the hazard curves for the 6 ground motion parameters (PGA and SA (T)), the uniform hazard spectra UHS for the three RP (500, 1000 and 2500 years) and the results of disaggregation 2D in terms of magnitude and distance (M,R) for the target motion given by the PGA , SA (0.2s) and SA (1s) for each RP. As example of these results Figure 5 presents the (M,R) contributions to the PGA for RP=500 years in each capital.

DISCUSION OF RESULTS AND CONCLUSIONS.

As main results derived from the analysis of the different maps its worthy to note that, for all return periods, maximum PGA values are predicted in the Panama Fracture Zone, south of Guatemala and certain zones of the volcanic chain. Isolines are quite parallel to the coast and PGA decreases towards the continent. An exception is observed at south of Guatemala, where PGA decreases slowly than in other countries, perhaps due to the influence of the Motagua fault**.** Maximun PGA values are: 600 gals for RP=500 y.; 700 gal for RP=1000 y. and 850 gal for RP= 2500y.
The morphology of the maps in terms of SA (0.2 s) is quite similar to the PGA maps, with maximum values around 1300, 1800 and 2000 gal for RP of 500, 1000 and 2500, respectively. However for SA (1s) the morphology changes, and higher hazard is predicted in coastal zones, the most extensive at southern Guatemala, making manifest the biggest influence of the subduction for the structural period of 1 s. Maximun values around 300, 400 and 500 gals are expected for the three respective RP.
Regarding the specific results in the capitals, derived from the hazard curves and UHS, we can observe that the highest hazard is expected in Guatemala city and San Salvador, followed by Managua and San Jose (quite similar) and notably minor in Tegucigalpa and Panamá.



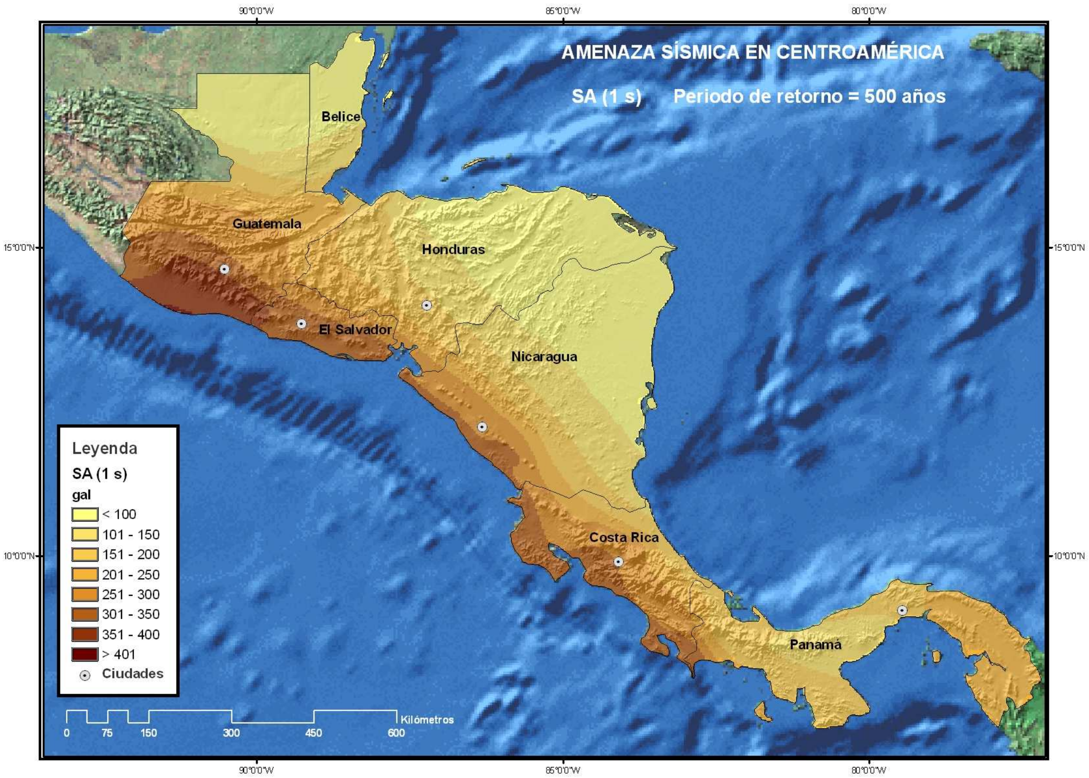


Figure 4. *Seismic Hazard maps of Central America for return period of 500 years obtained in this study, .Up. PGA (gal); Down: SA (1s) (gal)*

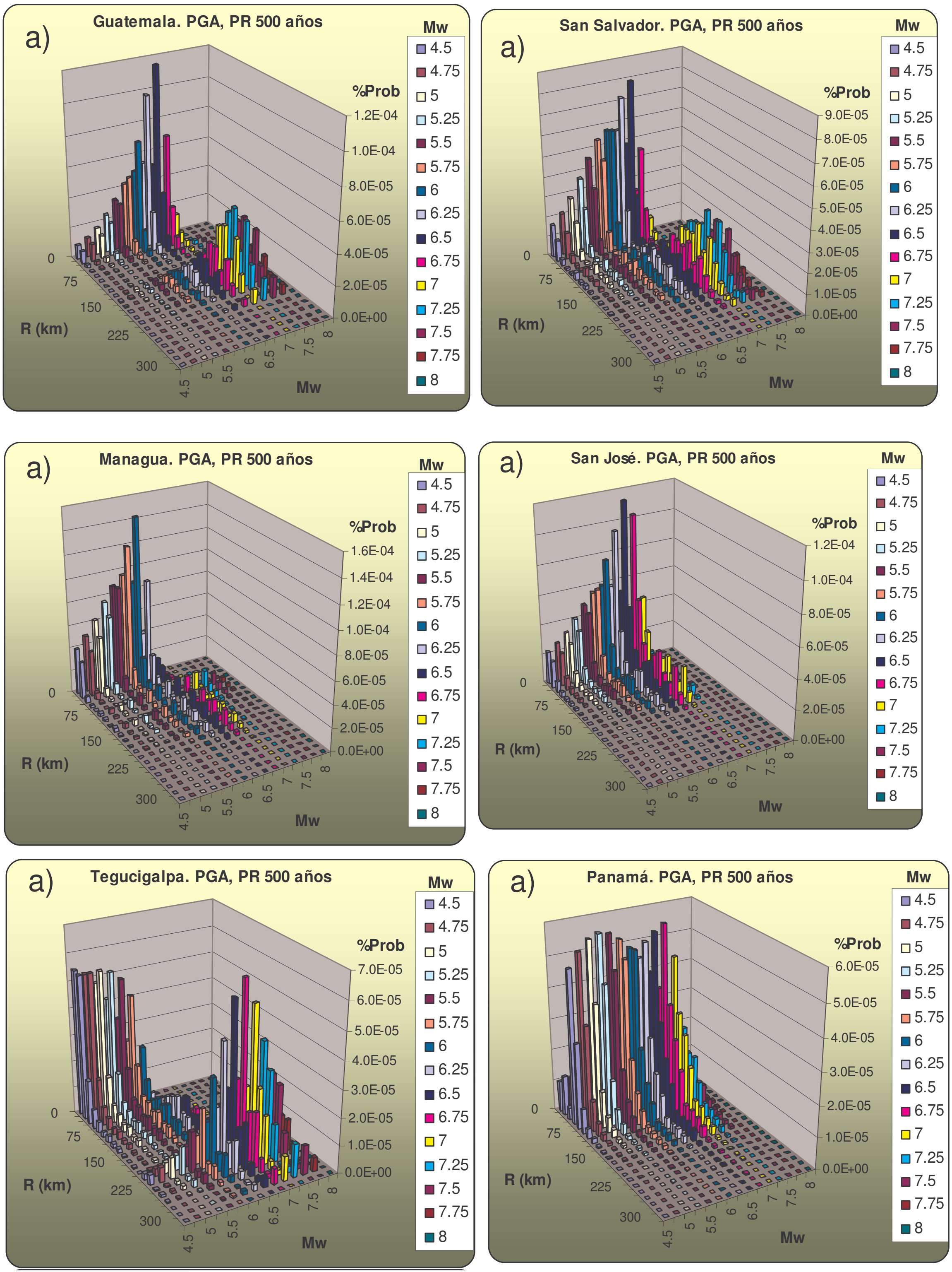


Figure 5. *Results of deagregation in the capitals of the 6 countries of Central America. Contributions of the couples (M,R) are represented for the target motion given by PGA for return period of 500 years.*

The analysis of the deagregation results allows to identify the control earthquakes associated to the dominant (M,R) couples. In some cases the graphics present bimodale distributions, making evident two possible control earthquakes at different distances. This is the case of Guatemala and San Salvador, with a mayor contribution of a moderate and near earthquake, identified with a crustal event in the volcanic chain, and other significant contribution of a higher magnitude and distant shock, which may be the subduction shock.In san Jose and Managua, hazard seems dominated by a local control earthquake with moderate magnitude, while in Tegucigalpa the dominant shock is a major and distant event, perhaps associated to the Motagua fault. In Panama doesn’t appear a clear control shock, but also ertahquakes in a range of M (4.5-7) and R(45-60 km). The quoted results refers to contributions for RP=5000y. in PGA, but tit is worthy to note that in some cases the results change with the RP and/or the structural period.

The hazard study presented here, the first done in terms of PGA and different SA (T) for the entire region, with the consensus of the seismologists of the different countries (in questions such as the seismic catalogue, zonation and attenuation models,etc). The results should be considered in the revision of the respective seismic codes.

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