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Estimated Human Losses in Future Earthquakes in Central Myanmar.

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I estimate that the city of Rangoon and adjacent provinces (Rangoon, Rakhine, Ayeryarwady, Bago) represent an earthquake risk similar in severity to that of Istanbul and the Marmara Sea region. The number of fatalities plus injured in a single future earthquake may exceed 100,000, possibly by much. After the M9.3 Sumatra earthquake of December 2004 that ruptured from central Sumatra to the Andaman Islands (e.g. Mignan, *et al.* 2006), the likelihood of additional ruptures in the direction of Myanmar, and within Myanmar, is increased (V. G. Kossobokov, M8-MSc Global Test communication). This assessment is especially plausible since M8.6 (Mar. 2005) and M8.2 and M7.9 earthquakes (Sep. 2007) extended the great 2004 rupture to the south. Given the dense population of the aforementioned provinces, and the fact that historically earthquakes of M7.5 class have occurred there (in 1858, 1895 and three in 1930), it would not be surprising, if similar sized earthquakes would occur in the coming decades.

INTRODUCTION

The World Agency for Planetary Monitoring and Earthquake Risk Reduction (WAPMERR) is a non-profit organization charged with assisting countries lacking extensive seismological expertise and international rescue agencies in mitigating earthquake disasters (www.wapmerr.org). It conducts a real-time service open to anyone interested in receiving emails containing loss estimates for earthquakes with M≥6 worldwide within less than one hour after the event. These estimates are also made available to the United Nations community via the GDACS website. In addition, WAPMERR calculates loss scenarios for regions of particular interest, in the hopes that mitigating measures may be taking where the predicted disaster may be serious.

Considering that I predicted the extent of human losses in the M7.6 Kashmir earthquake of October 2005 to a satisfactory degree six month before it occurred (Wyss 2005), it seems reasonable to attempt to estimate losses in future large to great earthquakes in central Myanmar and along its coast of the Bay of Bengal. I have calculated the expected number of fatalities for two classes of events: (1) M8 ruptures offshore, between the Andaman Islands and the Myanmar coast, and along Myanmar's coast of the Bay of Bengal (figure 1). (2) Repeats of the historic earthquakes (7.2≤M≤7.5) that occurred in the aforementioned years (table 2). The hypocentral depths are assumed to be 20 km for all events.

The number of persons injured is usually estimated in our real-time messages, but not discussed here. As an approximate rule, one may assume that there are twice as many injured as fatalities.

These calculations are only order of magnitude estimates because all necessary input parameters are poorly known. The population numbers, the condition of the building stock, the regional attenuation law, the local site amplification and of course the parameters of future earthquakes can only be estimated within wide ranges. For this reason, I give minimum and maximum estimates, both within approximate error limits.

A factor that reduces random errors in estimates of the total number of fatalities is the large number of settlements with large numbers of buildings and people (millions), in which case local over- and underestimates tend to hold the balance and yield an approximately correct over-all result.

The program used, QUAKELOSS, has been tested successfully during four years of loss estimates in near-real-time. After earthquakes with M≥6 worldwide, we distribute emails containing loss estimates within 41 minutes, in the median (Wyss 2004; Zibzibadze and Wyss 2008). The method is based on the work of Shakhramanian et al. (2000), and we have currently nearly completed a new version, QUAKELOSS2, that will be open source and available to any scientist for estimating losses. We focus on assisting developing countries and the world community to respond quickly and relatively well informed concerning probable human losses to earthquake disasters. A common problem in these countries is the poor quality of input data. For this reason, the program was calibrated to calculate human losses, using past earthquakes that have caused fatalities.

The over-all estimate of the number of fatalities is least sensitive to uncertainties in hypocenters for earthquakes on land, surrounded by numerous settlements of similar size because of the averaging process. The results are least reliable for ruptures offshore, at uncertain distance from large harbor cities.

The seismotectonic style of the part of Myanmar studied here is a mixture of strike-slip and normal faulting (Kumar, *et al.* 1996). The most prominent fault, the Sagain fault, accommodates right-lateral strike-slip motion, strikes NS and runs out to sea about 100 km NE of Rangoon. It is a transform fault that accommodates slip of about 6 cm/y, most of the motion of India with respect to Asia (Guzmanspeziale 1993; Krishna and Sanu 2000). Its southern segment has a length of 500 km and the maximum magnitude earthquake along it is estimated as M7.9 (Krishna and Sanu 2000). The region between the Sagain fault in the East and the subduction zone along the coast of the Bay of Bengal is producing shallow earthquakes of strike-slip and normal faulting, with historical magnitudes of up to M7.5.

METHOD

The program calculates the strong ground motion, expressed as intensity, as a function of the magnitude and distance from the hypocenter. The buildings in each settlement are assumed to be distributed into six fragility classes, according to the EMS-92 scale, in a way characteristic for the country and size of settlements in question. Based on the expected intensity of the ground motion, the resulting damage in six damage classes (ranging from minor damage, to total destruction) is calculated for each settlement. Finally the percentage of fatalities and injured in the damaged buildings is estimated, based on empirical relationships.

For each hypothetical earthquake, a minimum and a maximum for the number of settlements and people affected are obtained assuming average and good transmission properties for seismic waves, respectively. In the ranges given for human losses the uncertainties in fragility curves and the fatality rate in damaged buildings is included in addition to the uncertainty in attenuation properties.

The population numbers used for the large cities are those estimated for the year 2006 in the World Gazetteer. For the population in settlements too small to be contained in the World Gazetteer, the numbers from estimates in earlier years are increased at the same ratio the World Gazetteer assumes for growth in the large cities. The location and magnitudes of the historic earthquakes are taken from the US Geol. Survey list of significant events.

Approximate calibration for loss estimates along the Sumatra-Burmese plate boundary was provided by the two great earthquakes of 28 March 2005 and 12 September 2007. The estimates of fatalities distributed by WAPMERR in real-time are compared in table 1 with numbers reported from the field about a month later and with model calculations (figure 2) using the revised earthquake source parameters. The estimated number of fatalities depends strongly on the attenuation relationship used. Operating QUAKELOSS, the user can adjust parameters to model any attenuation law desired. The relationship used in the real-time calculations and that yields correct results in Sumatra closely resembles that for foreland earthquakes in Switzerland called ECOS (Fäh, *et al.* 2003). For ease of reference, we cite this relationship, although it was derived from small earthquakes and short distances.

The comparison in Table 1 shows that WAPMERR's real-time estimates were correct, within the precision necessary for decision makers concerning rescue operations, and that it is appropriate to use the ECOS attenuation relationship. Given the excellent agreement of the model estimates, we may proceed to estimate approximate losses for possible future earthquakes in the northern part of this plate boundary and in the adjacent mainland.

RESULTS AND DISCUSSION

The losses due to strong ground motion in the three scenarios with assumed offshore epicenters (S1 through S3) are expected to generate similar numbers of fatalities, in the range of 600 to 20,000, depending on their vicinity to sizable cities (table 2). The expected mean damage in the settlements in our database is shown in figure 3A for an M8 rupture of the plate boundary, starting at the Andaman Islands and propagating to near the coast of Myanmar. This might be the most likely of the events considered in table 2 because of its proximity to the great rupture of 2004.

The rational for expecting great earthquakes along Myanmar's coast along the Bay of Bengal has been outlined by Cummins (2007). In a great earthquake along this coast, the pattern of damage due to strong ground motion is expected to be strung out along the coast (figure 3B), with the extent of the disaster depending strongly on the distance of the rupture from shore and the vicinity of large coastal cities. Our estimates do not include victims of possible tsunami. In any of the scenarios 1 through 3, tsunami are likely (Cummins 2007) and the oceanic waves would add to the human losses I calculate due to strong ground shaking. The tsunami's devastating effects would be strongest along the Myanmar coast, but not negligible along the shores of Bangladesh and India. In this paper, these losses are not estimated.

Fatalities are expected at intensity VII and above. In table 2, the minimum and maximum numbers of settlements and population within the intensity VII areas are listed. This assists in understanding why scenarios with the same assumed earthquake magnitude produce different numbers of fatalities. The large cities most affected (table 2) are also giving a clue of why differences in disasters are expected as a function of epicenters. In the offshore scenarios, I estimate that about 50 to 500 settlements containing 160,000 to 2,600,000 people may experience shaking of intensity VII and larger (table 2).

For the M7.2 to 7.5 earthquakes on land considered here, the areas of intensity VII and larger contain about 100 to 500 settlements, and the populations range from 600,000 to 8 million, approximately (table 2). In the cases of earthquakes on land, the two events in the least populated regions (1858 and December 1930 repeats) yield similar estimates of 2,000 to 42,000 fatalities. The human losses are also similar in the two earthquakes surrounded by intermediate population density (May and July 1930 repeats), and the event proposed for scenario 4 (figure 3C). In these more populated areas, the range of fatalities is estimated as 6,000 to 90,000.

On land, the affected settlements and population are more or less evenly distributed around the epicenters (figure 3C). In these cases, the extent of the expected disaster does not much depend on the exact epicenter, but more on the unknown magnitude, the crustal and soil transmission properties and the time of day.

A possible repeat of the 1895 earthquake beneath Rangoon is the exception. In 1895 an M7.5 occurred close to Rangoon, the capital, which is estimated to have 4.7 million inhabitants today. In a repeat of such an earthquake (figure 3D), one would have to expect the number of injured plus fatalities to exceed 1 million (table 2). Luckily, the hope that such an event is not repeated soon is justified because the sequence of the 1895 to 1930 earthquakes may have dissipated the elastic energy sufficiently for delaying future ruptures in the region near Rangoon. Nevertheless, the possibility of an M6.5 class earthquake is always given. Even with such a moderate event, Rangoon could experience a major disaster, if the hypocenter is shallow and the epicenter close to the capital.

The fact that large and great earthquakes occurred along the Sumatra plate boundary in the 19th century before the seismic activity near Rangoon between 1895 and 1930 (Mignan, *et al.* 2006) might invite speculation that the recent great earthquake activity in Sumatra may be followed within a few decades by large earthquakes in central Myanmar. Although this is a reasonable assumption, there is no quantitative evidence that links earthquake activity in Sumatra with that in Myanmar.

CONCLUSIONS

I conclude that without possible tsunami impact, the hypothetical M8 earthquakes located offshore are expected to be less harmful than the M7.5 events on land: For M8 events offshore, the minimum number of fatalities is estimated as 800 ± 200 and the maximum is estimated as 13,000 ± 6,000. For repeats of the historic M7.5 or similar earthquakes, the minimum number of fatalities is about 4,500 ± 2,000 and the maximum is 58,000 ± 30,000. The number of injured can be assumed to equal about double the number of fatalities.

Although it is not very likely that the 1895 event near Rangoon would be repeated in the same location, it is evident that any medium to large earthquake in the vicinity of Rangoon could cause a major disaster with more than 10,000 fatalities.

In spite of the uncertainties in these estimates, it is clear that the capital of Myanmar, and the provinces surrounding it, will likely experience major earthquake disasters in the future, and the probability that these could occur during the next decades is increased. I conclude that major efforts of mitigation, using earthquake engineering techniques, and preparation for seismological early-warning capabilities should be undertaken in and near Rangoon, as well as in other cities of the region with more than 100,000 inhabitants (e.g., Phatein, Bago and Henzada).

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Table 1: Estimates of human losses distributed by WAPMERR via email in real-time after the two great earthquakes that extended the rupture of the Sumatra plate boundary to the south are compared with the eventual official fatality count, and with model loss estimates after the fact, using revised earthquake source parameters.

Earthquake	Source	Delay	Loss estimate
28 Mar. 2005 M 8.6	WAPMERR (real-time)	34 min	"alone due to strong shaking more than 1000 fatalities might occur, although the calculation suggests the [the] number may be below 1000"
28 Mar. 2005 M 8.6	USGS (Field reports)	1 month	Fatalities: 1,313
28 Mar. 2005 M 8.6	WAPMERR (estimate, minimum)	1 month	Injured: 2,140 to 4,900 Fatalities: 580 to 1400
12 Sep. 2007 M 8.4	WAPMERR (real-time)	31 min.	Injured Exp. min/max: 100 / 3,000 Fatalities Exp. min/max: 0 / 2,000
12 Sep. 2007 M 8.4	USGS (Field reports)	1 month	At least 25 people killed, 161 injured, 52,522 buildings damaged/destroyed
12 Sep. 2007 M 8.4	WAPMERR (estimate, minimum)	1 month	Injured: 130 to 440 Fatalities: 50 to 120

Table 2: Minimum and maximum of fatalities estimated for nine hypothetical large earthquakes, some of which might occur in Myanmar during the next few decades. The number of settlements likely to be shaken at intensity VII and larger are listed, along with their estimated population. Population and fatalities are given in thousands. The large cities most affected are listed in the last column.

Year	Month	Lat	Lon	M	Fatal min	Fatal max	Settl(VII) min	Settl(VII) max	Pop(VII) min	Pop(VII) max	Large City
1858	8	19.0	95.0	7.5	3.2	42.0	150	450	928	2,564	Myanaung
1895	1	16.8	96.2	7.5	107.0	1,100.0	130	340	6,538	8,450	Rangoon
1930	5	17.3	96.5	7.2	6.4	88.0	90	240	1,042	7,618	Bago
1930	7	17.4	95.5	7.5	6.6	84.0	200	500	1,852	9,558	Zalun
1930	12	18.2	96.4	7.3	2.2	28.0	90	280	606	2,020	Pyu
Scenario 1		15.9	93.9	8.0	0.6	8.4	50	176	176	1,167	none
Scenario 2		16.8	94.0	8.0	0.6	12.0	70	290	158	1,513	none
Scenario 3		17.7	94.2	8.0	1.1	19.1	130	530	718	2,632	None
Scenario 4		16.3	94.9	7.5	25.1	74.0	150	330	1,210	2,107	Kanbe

Figure 1: Map showing epicenters of historic earthquakes of magnitudes 7.2 to 7.5 (stars), epicenters of hypothetical future earthquakes (circles) labeled by scenario numbers (table 2), and locations of large cities judged to be strongly affected by possible repeats of historic or by scenario earthquakes (squares). The ellipse shows the possible extent and position of the scenario 1 rupture assumed here, and the rectangle outlines schematically the northern end of the mega-rupture of December 2004.

Figure 2: Mean damage state for the earthquake of 28 March 2005 (M8.6) estimated in an after-the-fact model calculation using the ECOS attenuation function. Given the excellent agreement of the total number of fatalities with the reported one, this case serves as a calibration for calculating losses further north along the same plate boundary. (Same legend as figure 3)

Figure 3: Map of settlements for which the mean destruction expected is indicated by a color code in case of hypothetical earthquakes for which the locations are marked by crosses in and near Myanmar (table 2). A) Scenario 1, B) scenario 3, C) scenario 4, and D) repeat of the 1895 earthquake near the capital. Case (B) shows the maximum, all other cases the respective minimum damage estimated. The mean damage to buildings is represented by a color scale with maximum of 5, showing six classes from less than 0.5 (minor damage) to more than 4.5 (total destruction).

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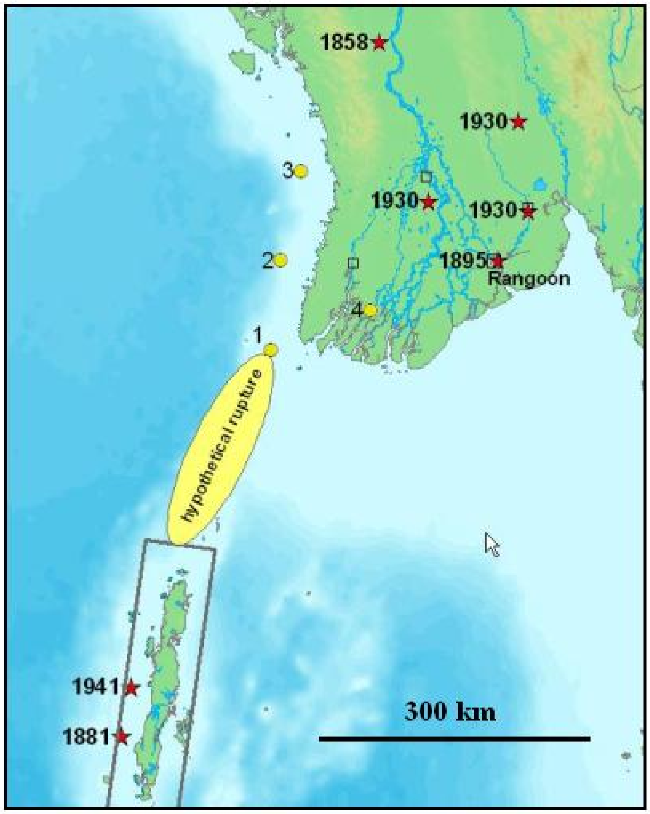
Figures



1858
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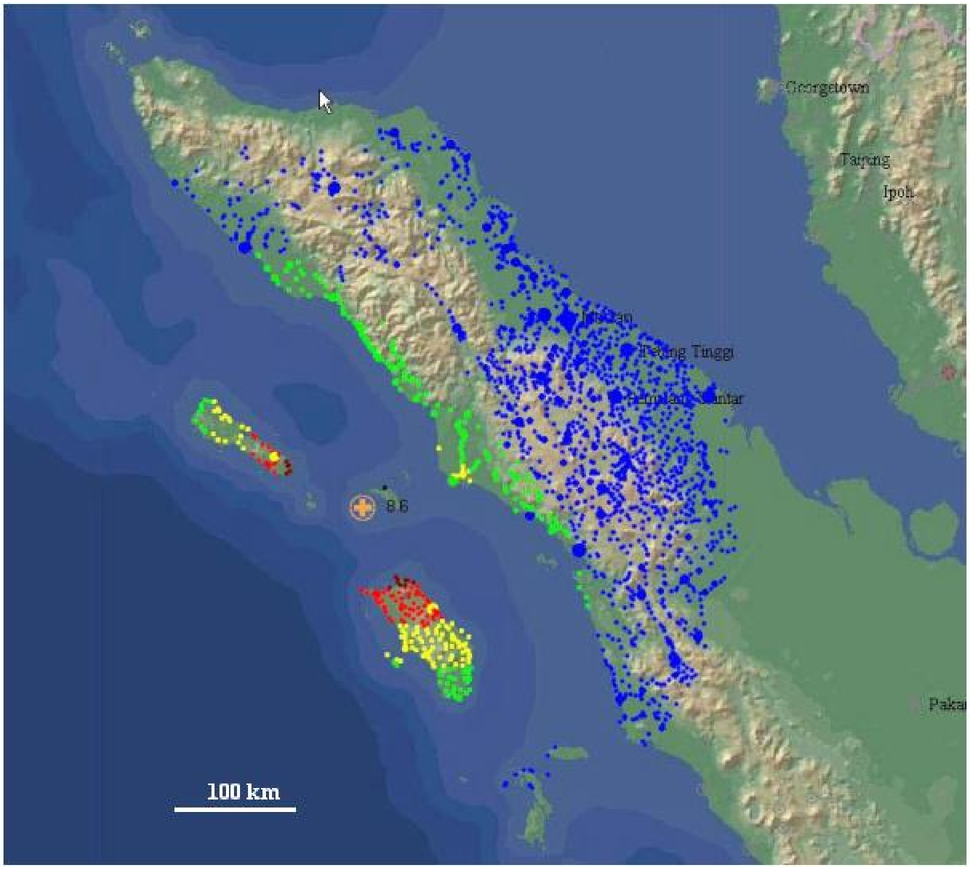
Georgetown
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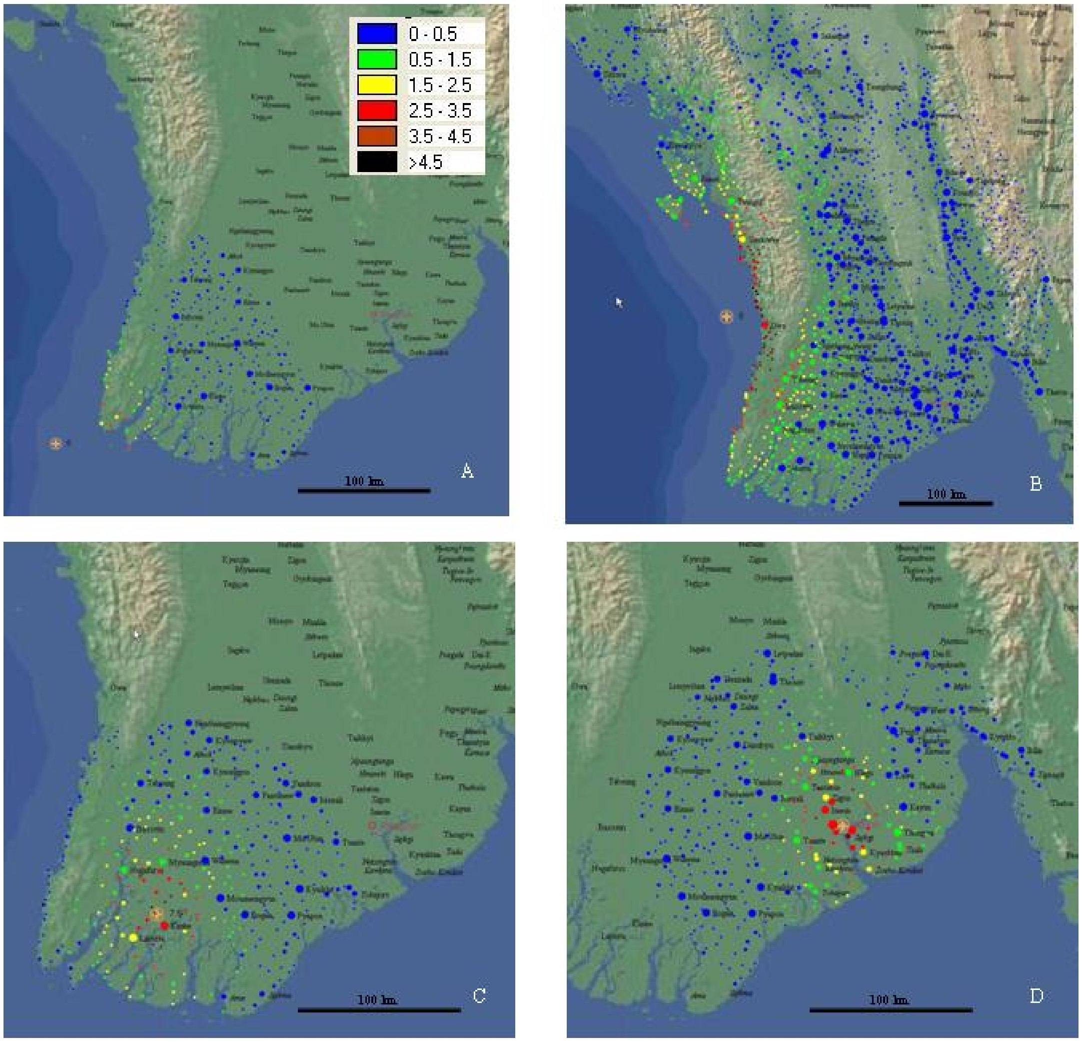
100 km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