Relative earthquake hazard in southwest Pacific cities

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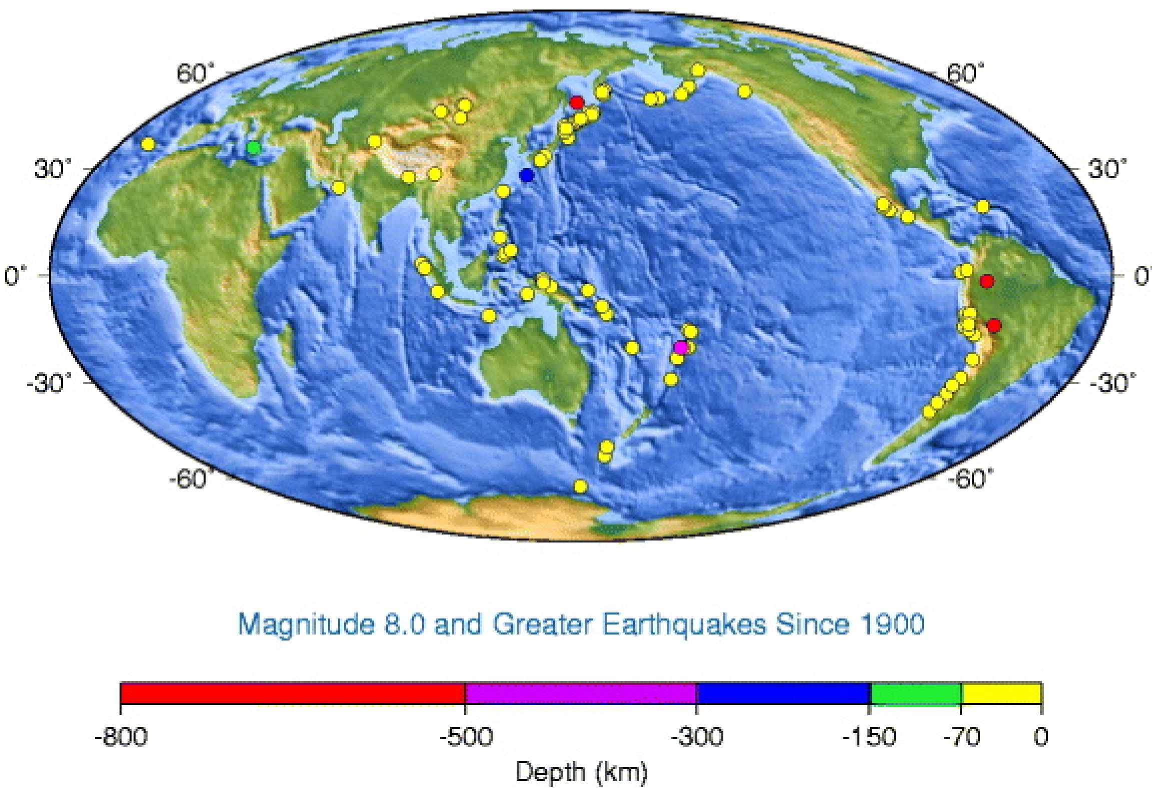
Abstract The southwest Pacific/Australian plate boundary impacts several cities, some of them national capitals; Auckland, Apia, Suva, Port Vila, Honiara and Rabaul. Earthquake hazard is high along the whole boundary but the return period of a $Mw9^+$ event appears to be more than 3000 years. There are few recordings of strong ground motion in any of these cities despite the high level of activity which can render PSHA results very uncertain. Historical records dating back 100 years or so provide an alternative hazard assessment metric, Modified Mercalli intensity. As an example, a recent PSHA for Port Vila is judged against the historical observations of intensity there and is found wanting.

Introduction The Southwest Pacific is a very active tectonic region with the potential to produce at least one great earthquake every decade (see Figures 1 to 3 and Table 1 below extracted from the ISC, USGS and GA world earthquake databases).



The convergence rate between the Pacific Plate and the Australian Plate increases from zero at the triple junction south of Macquarie Island to more than 100mm/yr just south of Samoa and 130mm/yr in the Bougainville/New Ireland region of Papua New Guinea. The seismic moment release is proportional to the rate of collision.

With virtually a single arc segment extending 2000km north from New Zealand 38ºS to Samoa (15ºS), more than double the length of the Sumatran arc segment, it is surprising that the largest known earthquake since 1900 has a magnitude of only 8.5. The arc segment south of New Zealand to the triple junction had no great earthquakes in nearly 90 years until 1989 and then suffered two in the next 15 years (see Table 1). The New Zealand segment has suffered no great earthquakes in the instrumental period post-1901, but a great magnitude 8.1 earthquake occurred in the North Island in 1855. Thus the lack of mega earthquakes on the Kermadec/Samoa segment is no reason to suppose they can't or won't happen. The Vanuatu and Solomon Is arcs are shorter, about 1000km long.

Table 1 Great M8+ earthquake in the SW Pacific since 1900. Search parameters 0 – 55S, 150E – 165W, 19010101 – 20091231 (109 years). Combination of ISC, USGS GA and E&V databases

Date	*Time*	*Latitude*	*Longitude*	*Depth*	*Magnitude*	*Source*	*Place*
1910/06/16	06:30:42	-19.0	169.5	100	MS8.1	PAS	Vanuatu
1917/05/01	18:26:30	-29.0	-177.0	35	Mw8.0	P&S	Kermadec
1917/06/26	05:49:42	-15.5	-173.0	35	Mw8.5	P&S	Tonga
1919/04/30	07:17:05	-19.0	-172.5	35	Mw8.2	P&S	Tonga
1977/06/22	12:08	-22.91	-175.75	64	Mw8.1	HRV	Tonga
1989/05/23	10:54:46.2	-52.51	160.60	10	Mw8.1	HRV	Macquarie Is
2000/11/16	04:54:56.1	-3.97	152.18	28	Mw8.0	HRV	New Ireland
2004/12/23	14:59:04	-50.24	160.13	10	Mw8.0	GA	Macquarie Island.
2007/04/01	20:39:56	-8.47	156.95	10	Mw8.1	USGS	Solomon Is
2009/09/29	17:48:08.0	-15.57	-172.08	0	Mw8.1	USGS	Samoa

Table 2 Events not used in recurrence relation (but on one or other of the databases)

1903/01/04	05:07	-20.0	-175.0	400	8.0	B&D	Tonga
1920/09/20	14:39:00	-19.92	168.53	35	Mw7.8	P&S	Vanuatu
1934/07/18	19:40:15	-11.91	166.73	35	Mw7.8	P&S	Santa Cruz
1939/04/30	02:55:30	-9.30	159.23	35	Mw7.9	P&S	Solomon Is
1950/12/14	01:52:47	-19.500	-176.000	200	Ms8.1	GA	
1955/02/27	20:43:23	-28.250	-175.000	0	Ms8.0	GA	
1957/04/14	19:18:00	-15.000	-173.250	0	Ms8.0	GA	
1971/07/14	06:11:28	-5.517	153.865	43	Ms8.0	GA	Bougainville
1971/07/26	01:23:21	-4.933	153.182	43	Ms8.0	GA	
2000/11/17	21:01:56	-5.45	151.685	33	Ms8.0	GA	New Britain region, PNG
2009/09/29	17:48:10.7	-14.8000	-171.5700	16	Ms8.1	BJI	Samoa Islands
2009/09/29	17:48:12.9	-15.7730	-171.6810	33	mb8.2	GRF	Samoa Islands region
2009/09/29	17:48:13.0	-15.4000	-172.1400	33	MS8.3	MOS	Samoa Islands region
2009/09/29	18:22:11.6	-16.1008	-173.2328	0	MS8.7	IDC	Tonga Islands

Note there were 80 shallow M8+ earthquakes worldwide in this time.

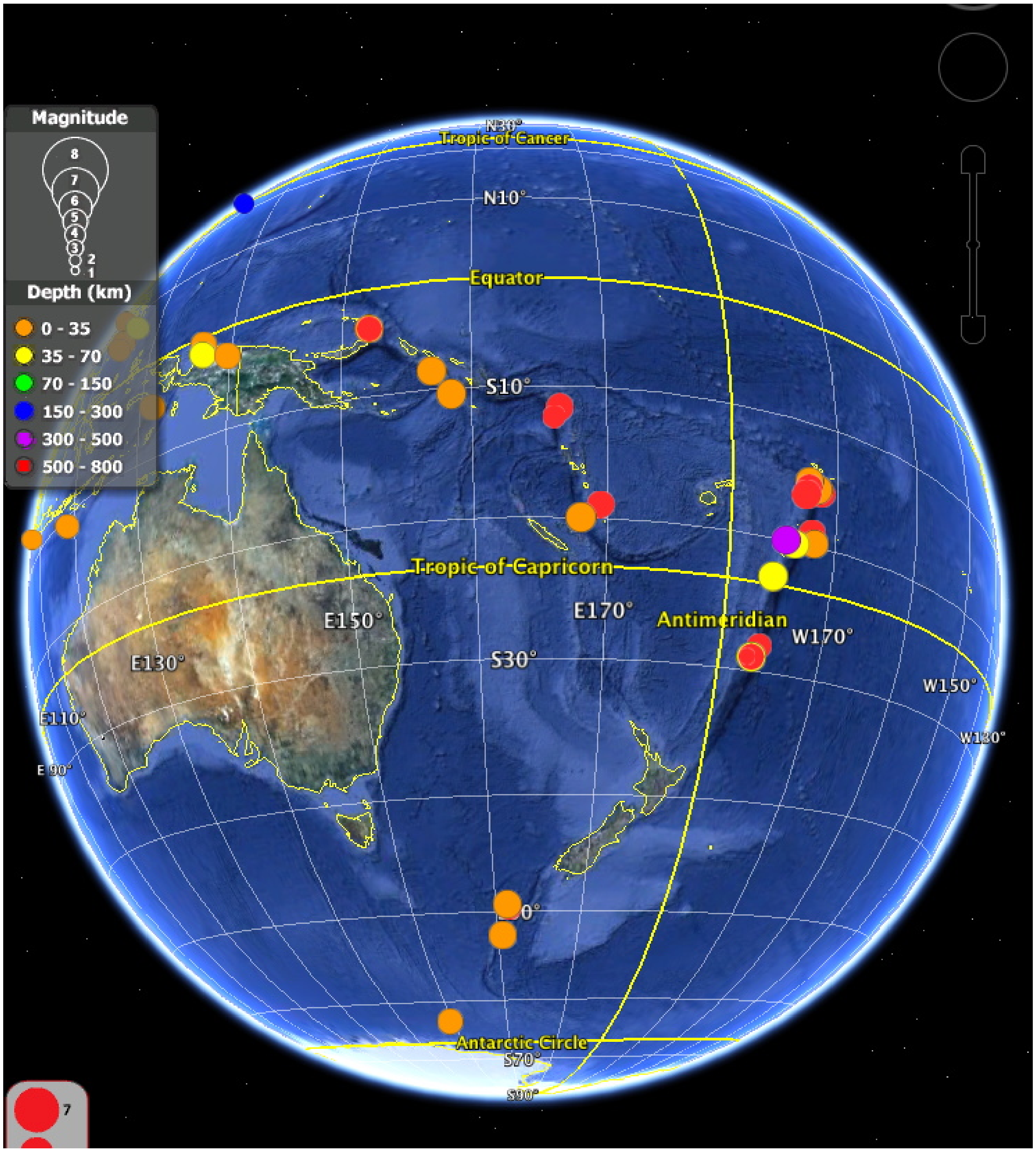


Figure 2 Magnitude 8+ earthquakes in the Southwestern Pacific since 1900

Recurrence Relation The cumulative number of earthquakes per year along the SW Pacific plate boundary can be simply calculated once the database has been carefully vetted for spurious and missed events (Figure 3 below). The events in Table 2 have not been used because they are too deep or have an unreliable magnitude or didn't happen. They are listed because others will also find then in a search and wonder why they haven't been used in my analysis. The magnitude problem is significant, the 1910 event has a magnitude range of 8 to 8.6 so I have not attempted to convert the 1910 Pasadena Ms to Mw, the two are virtually equivalent at this magnitude. For a hazard analysis, this approach would have to be used for each segment of the plate boundary. They have all been lumped together here to document the high activity of the Southwest Pacific and to compute the apparent return period for a magnitude 9 earthquake there.

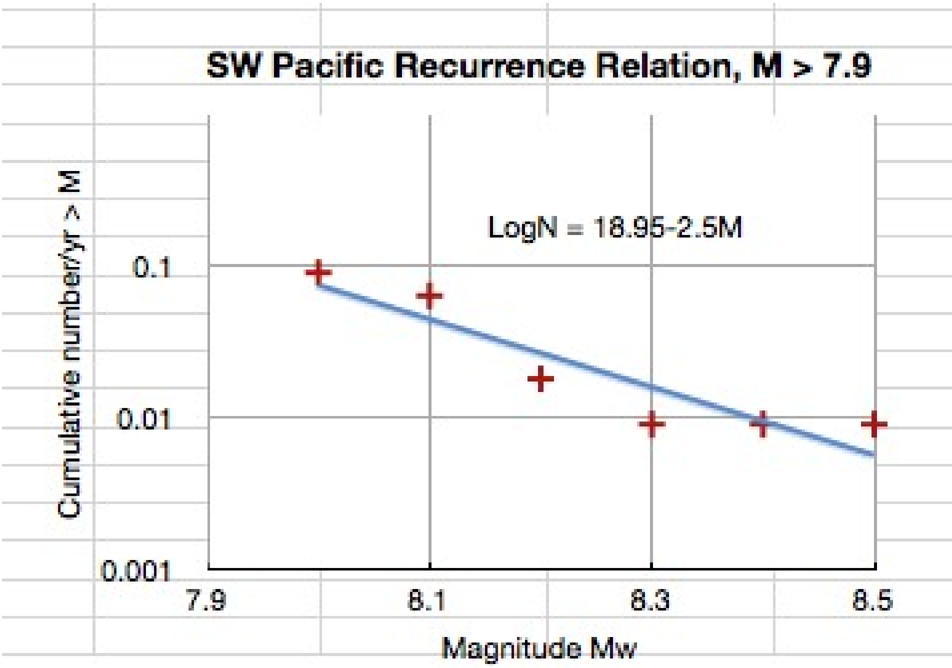


Figure 3 Recurrence relation for great earthquake on the Pacific/Australian Plate boundary between New Ireland PNG and the triple junction south of Macquarie Island at about (61ºS, 162ºE) since 1900.

The 'b' value is about 2.5 in the magnitude range 8.0 to 8.5, much higher than in the magnitude 6 to 7 range where it is globally about 1.0. Extrapolating to Mw 9 we get a very long return period, more than 3000 years.

Earthquake Risk by PSHA To develop a risk analysis for each country in the SW Pacific, you need to specify local source zones within which the tectonic style is similar and earthquake rate is constant and in each source zone, produce a recurrence and strong motion attenuation relationship (Cornell, 1968). It is not the purpose of this paper to complete this process but to suggest an alternative.

The subduction tectonic environment is similar along this whole plate boundary, with the subduction direction flipping from one side to the other, except along the two transform fault segments through Fiji and southern Solomon Is in the vicinity of Santa Cruz. It is probable that an attenuation relationship appropriate for a subduction zone in any one country (such as New Zealand) would be appropriate for all. Since there is no strong motion data available anywhere except in New Zealand (apart from a few valuable records in Papua New Guinea) this is a reasonable hypothesis. That is why it is very important that all recorded strong motion data be made publicly available.

A specific and thorough study of earthquake hazard, as a prelude to a risk analysis, is required in each country in the SW Pacific, nothing more, nothing less.

Alternative risk analysis to PSHA With 100 years of observation and recording, it is possible to use the felt intensities to generate a risk analysis that should be sufficient for normal buildings and structures (ie not dams or electricity substations, hospitals or schools).

When Cornell (1968) published his seminal paper on earthquake risk, he used modified Mercalli intensity as well as peak ground velocity and peak ground acceleration (pga) to characterise hazard, though it is more normal to use a spectral ordinate at some other frequency (pga is the zero frequency spectral ordinate) or a uniform hazard spectrum today if adequate strong motion data is available. If you have to guess the attenuation relationship, local site foundation conditions and make assumptions about how the fault rupture will propagate you might just as well use observed intensities and an empirical conversion equation between intensity and pga for example.

An example: Port Vila

Special studies of earthquake hazard have been attempted in Papua New Guinea, Vanuatu, Fiji, Samoa and most thoroughly in New Zealand. Inspection of the tectonic setting of all the cities in the SW Pacific indicates that Port Vila sited on the island of Efete, Vanuatu probably has the highest rating for earthquake hazard. Vanuatu is adjacent to the interface of the Australian and Pacific Plates, the subduction zone dips east beneath Efete, the trench only 50 km west of Port Vila.

A recent study of earthquake hazard in Vanuatu by Suckale and Grunthal (2009) allows us to compare the two methods. They used a PSHA with no locally recorded strong motion data (either acceleration or intensity). This study uses an extreme-value distribution based on 55 years of observed intensities converted to pga.

There are problems with both approaches, the main one the lack of recorded strong motion data. This report is based on a linear fit to the 55 years of historical intensity data and it should not strictly be extrapolated linearly to return periods much longer than a hundred years, one or two times the data collection interval, and there is no assumed maximum intensity though the scale is saturated at MM XII. The PSHA by Suckale and Grünthal (2009) has in-built maximum magnitudes varying from 6.4 to 8.3 for different source zones, causing the hazard estimate to approach an asymptote at long return periods, they don't increase linearly with time.

The values of maximum magnitudes Suckale and Grünthal (2009) assumed are not conservative. Higher Mmax values would increase their hazard estimates at long return periods (> 500 years). One surprising result is their 'b' value, the slope of their recurrence relationships, mostly about 0.7 which is lower than the expected value of around 0.95 to 1.0. This is probably a result of their magnitude scale conversion equations (mb and Ms to Mw).

I have reproduced the hazard curve results of Suckale and Grünthal (2009) for Port Vila in Figure 4 to compare with this study in Figure 5.

To compile the necessary observations of intensity at Port Vila I searched the ISC and USGS earthquake catalogues and tabulated each reported intensity, the first in 1927. There was a big gap to the next observation of intensity so I have started from 1955 after which there are regular reports, almost every year. It is interesting that only this year on

10 August 2010 was the damage sufficient for local seismologists to assign an intensity of MM 7 following a magnitude 7.3 earthquake, it's epicentre only 35 km east of Port Vila. Here is a media report: *Local residents said the earth shook for about 15 seconds but did not appear to have caused significant damage. "It wasn't too much. Everything's fine," a Port Vila hotel employee said, referring to the shaking.*

This intensity of MM 7 is probably the strongest shaking observed in 100 years at Port Vila based on recorded seismicity if not actual observations of damage or intensity. Suckale and Grunthal predict a 10 yr pga of 0.25g and 100 yr pga of 0.4g to 0.6g. My results show that the expected 10 yr intensity is about MM V and the 100 yr intensity about MM7 just as observed. This is a big difference in hazard estimation. Using Atkinson and Kaka (2007) to convert from intensity to pga we obtain predicted ranges 0.015 to 0.1g and 0.16 to 0.3g respectively for the 10 year and 100 year pga, a factor of 2 or more difference.

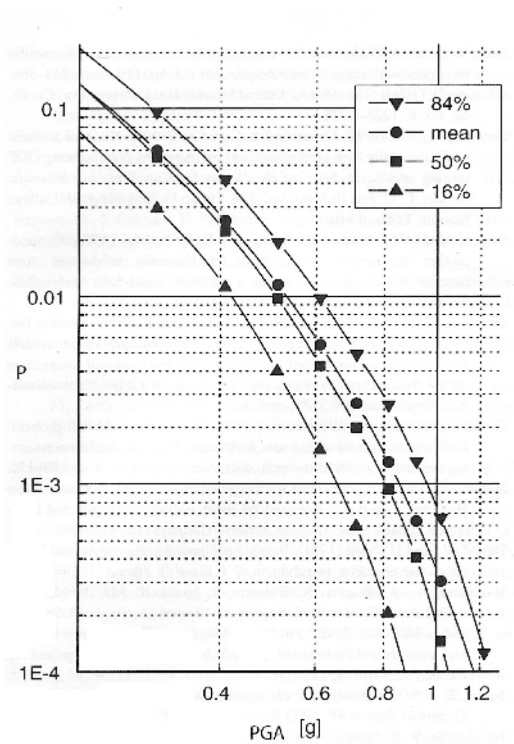
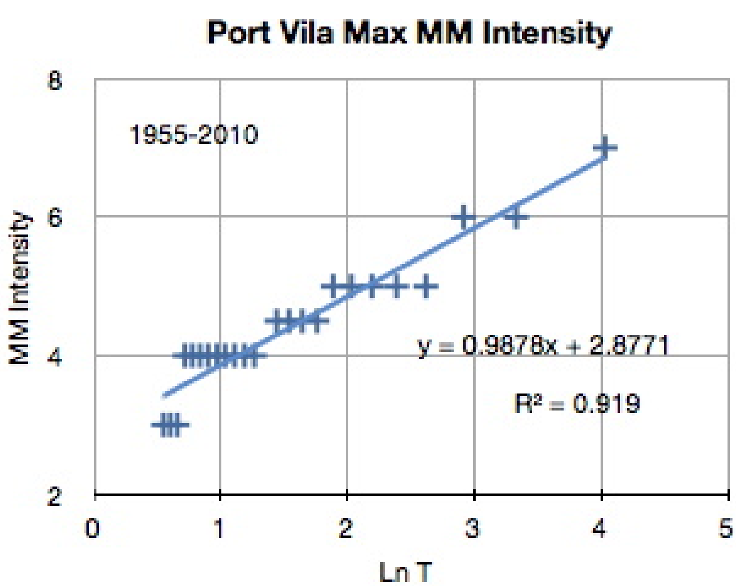


Figure 4 Port Vila PSHA result from Suckale and Grunthal (2009)

Figure 5 Extreme value plot of reported Port Vila intensities



We acknowledge that pga is a poor measure of damage but was used in the instance to compare with the PSHA study. It is considered likely that a pga to MM intensity relationship is independent of tectonic setting given the huge scatter in such relationships.

Discussion

A megathrust earthquake of magnitude 9 or more in the SW Pacific could be considered by disaster managers as a maximum credible event in any hazard analysis, the tsunami risk inference is obvious though not discussed in this paper.

When there are no observations of strong ground shaking during an earthquake in a remote environment, the results of a PSHA have to be critically reviewed, in the very least the uncertainties in mean values must be expected to be very high. The only way to do a reality check is by using observed intensities with all the problems of conversion to some more useful number like pga that this ensues.

Insurance companies seem to be happy using intensity and in countries with no strong motion data, today's engineers will have to get used to following suit until they convince governments and developers to install instruments as part of their project proposal.

An extreme value plot of intensities predicts much lower ground shaking than the PSHA. It seems from the intensity observations that attenuation is very high across the subduction interface at Port Vila and by inference, everywhere in the SW Pacific.

Strong motion instruments should be installed in the cities of all SW Pacific countries as soon as possible to take the guesswork out of future PSHAs.

Acknowledgment

Thanks to the anonymous reviewers for constructive comments which I have attempted to address.

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