Questionnaires for experts- weighting schemes

Expert Elicitation for S-PTHA

Athens, Greece

6/30/2016

Following the Senior Seismic Hazard Analysis Committee definition, the goal of any assessment of public relevance should be the quantification of “*the center, the body, and the range of technical interpretations that the larger technical community would have if they were to conduct the study*” (SSHAC 1997). The critical point for this quantification is the capability to measure the strength of all the opinions emerging in the context of the "larger technical community".

This document contains two weighting schemes we’ll use in TSUMAPS-NEAM to assign weights to the Panel of Experts.

The first weighting scheme is based on questions related to the Seismic Probabilistic Tsunami Hazard Assessment (S-PTHA).

The questions are intentionally very precise, and the experts are not expected to know the exact answers to each of those questions.

We ask you to answer these questions providing your best and uncertain estimates. The best guess will be expressed by 50th percentile (median) and confidence interval by 5th and 95th percentiles.

For each question, a short description is given. A literature reference where the answer can be found is also given. The goal is to ‘measure’ how each expert deals with his/her personal uncertainty within his/her area of expertise.

The answers of an individual expert will never be disclosed, except for the individuals strictly analysing the data (J Selva, S. Iqbal, H.K. Thio, S. Lorito) for conducting the experiment.

In the second weighting scheme, the experts are requested to vote to each other.

The list of the names of the Pool of Experts (PoE) is provided. Each expert should vote himself and two other colleagues with weights either 1 or 3.

The outcome of this activity, as weighting of experts’ opinions, will be used in expert elicitation being conducted within TSUMAPS-NEAM. The outcome of these questionnaires will be always presented in an aggregated form, or in a completely anonymous way.

Expert´s name: ______________________________

Affiliation: _______________________________

Performance-based weighting scheme

Question 1

The Atlantic segment of the Africa-Europe plate boundary has usually been interpreted as a transform boundary on the basis of the bathymetric expression of the Gloria fault and dextral strike-slip first-motion mechanisms aligned along the Azores-Gibraltar line of seismicity. The May 26, 1975 earthquake (Ms=7.9) was assumed to fit into this framework because it occurred in the general area of this line and has a similar first-motion focal mechanism (strike=288", dip=72", slip angle=184"). However, several anomalies cast doubt on this picture: the event is abnormally large for an oceanic transform event; a sizeable tsunami was excited; the aftershock area is unusually small for such a large event; and most significantly, the epicentre is 200 km south of the presumed plate boundary. The Rayleigh wave radiation pattern indicates a change in focal mechanism to one with a significant dip-slip component. The short duration of the source time history (20 s, as deconvolved from long-period P-waves), the lack of directivity in the Rayleigh waves, and the small one-day aftershock area suggest a rather small fault length. Lynnes and Ruff (1985) noted that the short rupture duration and fault length present a sharp contrast to other large strike-slip earthquakes. The aftershocks are unusually small in size and number for an event of such magnitude. There is only one of magnitude greater than 5, and only 15 within the first day. The areal extent of the one-day aftershock area is also small, again implying a short fault length. Although the ISC locations are somewhat scattered, the master-event relocations fall quite close to the main shock: none relocate further than 71 km away and all but two fall within about 40 km. Taking a shear modulus of 400 kbar, a fault length of 80 km and a fault width of 20 km, Lynnes and Ruff (1985) obtain a stress drop of 140 bar and a very large displacement.

Considering the same computational framework presented for the stress drop, following Lynnes and Ruff (1985), which was the computed displacement (m)?

To express your best guess and confidence interval estimates associated with earthquake co-seismic displacement in m, please provide the 5th, 50th, and 95th percentiles in the following table.

Percentiles:	5th (min)	50th (best guess)	95th (max)
Estimate (m):			

Reference: Lynnes CS and Ruff LJ (1985), Source process and tectonic implications of the great 1975 North Atlantic earthquake, Geophys. J. R. astr. SOC. (1985) 82, 497-510.

Question 2

Following the review of Satake & Atwater (2007), the giant 1960 Chile earthquake culminated into a series of fault displacements that began 29 h earlier, with a foreshock of Mw 8.1 (Cifuentes 1989). The series also included a slow earthquake ∼15 min before the mainshock. The mainshock itself has a range of estimated sizes. Kanamori (1977) used 2×10^{23} Nm as an average estimate of seismic moment; the corresponding moment magnitude of 9.5 has become the generally accepted estimation for this earthquake. However, the seismic moment estimated from free oscillations and strain seismograms spans the range $1–3 \times 10^{23}$ Nm, equivalent to Mw 9.4–9.6 (Kanamori & Cipar 1974, Kanamori & Anderson 1975, Cifuentes 1989, Cifuentes & Silver 1989).

Based on the analysis of the distribution of aftershocks and crustal deformation, Cifuentes (1989) estimated also the rupture length of the mainshock, with an uncertainty range of +/- 100 km. What was Cifuentes's best guess value for the rupture length?

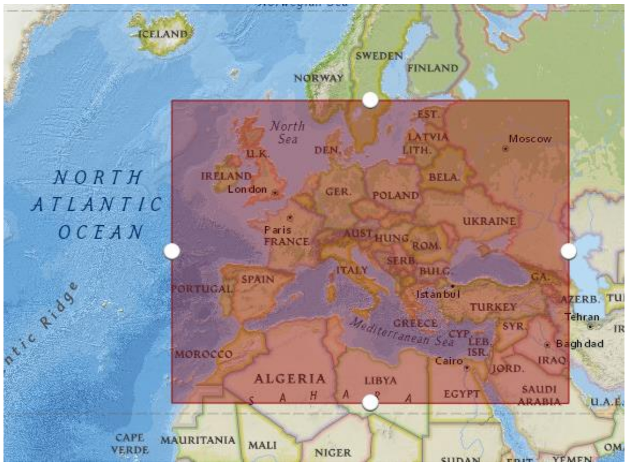
To express your best guess and confidence interval estimates associated with <u>rupture length in km,</u> please provide the 5th, 50th, and 95th percentiles in the following table.

Percentiles:	5th (min)	50th (best guess)	95th (max)
Estimate (km):			

Reference: Cifuentes IL (1989), The 1960 Chilean Earthquakes, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 94, NO. B1, PAGES 665-680, JANUARY 10, 1989.

Question 3

It is estimated that several millions earthquakes are recorded every year. Many go undetected because they hit remote areas or have very small magnitudes. As more and more seismographs are installed in the world, more earthquakes can be and have been located. According to USGS ANSS Comprehensive Catalog, the number of recorded “moderate” earthquakes (magnitude 5.0 or greater) has stayed relatively steady in the last decades of the last century. From 1970-1999, (30 years), 758 earthquakes with M >= 5 *(*)* occurred in the European area (latitude between 25 and 60, longitude between -17 and 48, see figure).



According to the same catalog, how many “strong” earthquakes (N) occurred in the same period (30 years) and in the same area (European area) with M >= 6.0?

To express your best guess and confidence interval estimates associated with <u>the number of earthquakes with M >= 6,</u> please provide the 5th, 50th, and 95th percentiles in the following table.

Percentiles:	5th (min)	50th (best guess)	95th (max)
Estimate (N):			

Reference: United States Geological Survey (USGS), ANSS Comprehensive Catalog (http://earthquake.usgs.gov/earthquakes/search/).

(*) The magnitude reported is that which the U.S. Geological Survey considers official for this earthquake, and was the best available estimate of the earthquake’s size, at the time that this page was created. Other magnitudes associated with web pages linked from here are those determined at various times following the earthquake with different types of seismic data. Although they are legitimate estimates of magnitude, the U.S. Geological Survey does not consider them to be the preferred "official" magnitude for the event.

Question 4

Geist & Parsons (2014) examined the effect of under-sampling on estimating the size of extreme natural hazards from historical data. A total of 4,283 earthquakes are analyzed. Two global dataset have been considered: one for the sub-catalog up to, but not including, the December 26, 2004 m w = 9.0 Sumatra–Andaman earthquake and one for the entire catalog. By jointly estimating the parameters of a tapered Pareto (β and the corner magnitude *Mc*) distribution through MLE, it is found that while β results consistent between the two catalogs, the *Mc* parameter does changes significantly. In particular, it is found that for the 1982–2004 catalog a pure Pareto parent distribution can be rejected with confidence, while when more recent earthquakes are included, the pure Pareto distribution cannot be rejected. Similar conclusions were reached by Zöller (2013) in a statistical analysis of the entire global CMT catalog.

The MLE (Maximum Likelihood Estimation) quantification of β is 0.64 for both catalogs and is well constrained, although Kagan (2010) describes several factors that cause an upward bias in the estimate of b for earthquakes. The estimates of *Mc* for the 1982–2004 is 8.11. Following Geist & Parsons (2014), which is the MLE estimate of *Mc* for the 1982–2008 catalog?

To express your best guess and confidence interval estimates associated with the corner magnitude *Mc* for the 1982-2008 catalog, please provide the 5^{th}, 50^{th}, and 95^{th} percentiles in the following table.

Percentiles:	5^{th} (min)	50^{th} (best guess)	95^{th} (max)
Estimate (%):			

Reference: Geist, E.L., and Parsons, T., 2014, Undersampling power-law size distributions: effect on the assessment of extreme natural hazards: Natural Hazards, v. 72, p. 565-595, doi:10.1007/s11069-013-1024-0

Question 5

The 2 June 1994 Java earthquake occurred off the southern coast of Java, Indonesia. The source area was very close to the Sunda trench, and just beneath a very steep oceanic slope. According to Tanioka & Satake (1996), by choosing a 15° dipping fault plane from the Harvard CMT for this earthquake, the resulting calculated horizontal deformation due to thrust faulting is larger than the vertical deformation. By using an Okada-like algorithm and an approximated expression for the calculation of the additional vertical displacement due to the horizontal movement of the slope, Tanioka & Satake (1996) find a maximum amplitude for the total vertical displacement, due to the combined effect of faulting and of slope movement, of 1.29 m. They use an average slip of 3.24 m and a realistic bathymetry.

What's the fraction (between 0 and 1) of the maximum total vertical displacement due to the contribution of the slope movement?

To express your best guess and confidence interval estimates associated with the fraction of maximum vertical displacement, please provide the 5^{th}, 50^{th}, and 95^{th} percentiles in the following table.

Percentiles:	5^{th} (min)	50^{th} (best guess)	95^{th} (max)
Estimate (fraction):			

Reference: Tanioka Y & Satake K, Tsunami generation by horizontal displacement of sea bottom, GRL, 23, 861-864, 1996.

Question 6

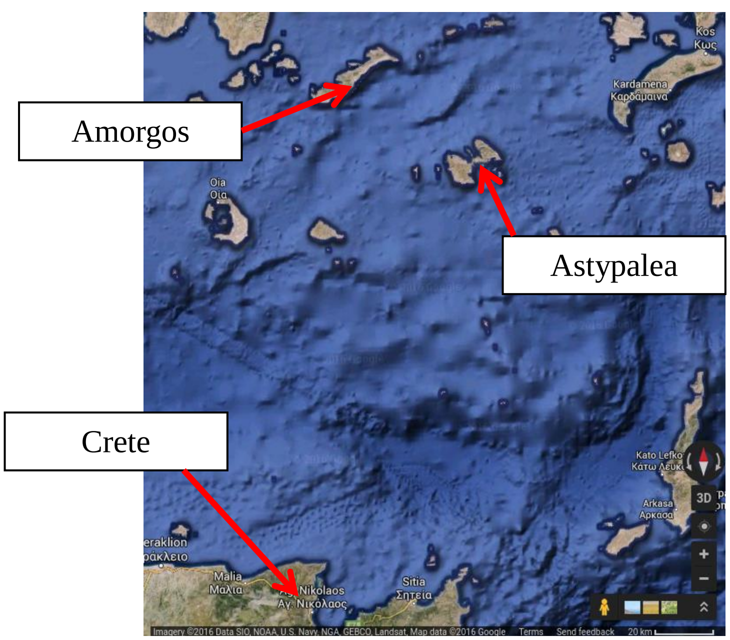
One of the largest tsunamis that occurred in Greece in recent times was the so-called Amorgos tsunami, on the 9th July 1956. According to Papazachos & Dimitriu (1991), this tsunami was caused by an earthquake of Ms = 7.5, with epicenter between Amorgos and Astypalea Islands (see figure below), and "the sea-wave height reached 25 m at the southern coast of Amorgos Island" and "2.6 m at the eastern coast of Crete".

According to Papazachos & Dimitriu (1991), which sea-wave height was reached at the Northern Coast of Astypalea Island?

To express your best guess and confidence interval estimates associated with <u>the maximum sea-wave height in m,</u> please provide the 5th, 50th, and 95th percentiles in the following table.

Percentiles:	5th (min)	50th (best guess)	95th (max)
Estimate (m):			

Reference: B. C. PAPAZACHOS and P. P. DIMITRIU, Tsunamis In and Near Greece and Their Relation to the Earthquake Focal Mechanisms, Natural Hazards 4: 161-170, 1991.



Question 7

On March 11, 2011 in Japan, a magnitude 9.0 earthquake occurred off the northeast coast. This earthquake generated a tsunami that struck Japan as well as various locations around the Pacific Ocean. The generated tsunami produced waves of significant height.

Following Mori *et al.* (2011), what was the maximum recorded inundation height of tsunami waves on the Sendai Plain (Japanese territory)?

To express your best guess and confidence interval estimates associated with <u>the maximum recorded inundation height of the waves in meters (m),</u> please provide the 5^{th}, 50^{th}, and 95^{th} percentiles in the following table.

Percentiles:	5^{th} (min)	50^{th} (best guess)	95^{th} (max)
Estimate (m):			

Reference: Mori N *et al.*, "Survey of 2011 Tohoku earthquake tsunami inundation and run-up", Geophysical Research Letters 38-7 (2011)

Question 8

In the past centuries some areas of Southern Italy were struck by important tsunamis mainly generated by regional seismic sources (earthquakes, submarine earthquakes) and non-seismic sources (landslides and total or partial collapse of volcanic edifices due to volcanic eruptions).

The Italian Tsunami Catalogue ITC (Tinti et al. 2004) reports the earthquakes and slides causing tsunami in the last 500 years. Other studies (Maramai et al. 2005a, b; Favalli et al. 2009; Tinti et al. 2007) provided further and more recent information about the historical events. In a further analysis, Grezio et al. (2012) listed the earthquake events, and the mass failures occurred in the last 500 years with: (1) a tsunami reliability equal to 4, meaning that a definite tsunami occurred, and (2) a tsunami intensity =2 and C3 in Ambraseys-Sieberg Scale. An event of intensity C3 is generally recognized to produce run-ups of approximately 1 m (Tinti et al. 2005), and Grezio et al. (2012) assumed that the impact of the tsunami wave could reach all key sites grouped in the correspondent sub-region of the ITC catalogue. Following this procedure, they found 21 tsunami events to be considered for the likelihood of their Bayesian procedure.

Out of the 21 events producing tsunami in MSA in the last 500 identified by Grezio et al. (2012), how many have been identified by the authors of seismic origin?

To express your best and confidence interval estimates associated with the number of tsunamis with impact on MSA in the last 500 yr, please provide the 5^{th}, 50^{th}, and 95^{th} percentiles in the following table.

Percentiles:	5^{th} (min)	50^{th} (best guess)	95^{th} (max)
Estimate (num):			

Reference: Grezio A, Sandri L, Marzocchi W, Argnani A, Gasparini P, Selva J (2012), Probabilistic Tsunami Hazard Assessment for Messina Strait Area (Sicily - Italy), Nat. Haz. 64:329-358, DOI: 10.1007/s11069-012-0246-x

Question 9

The NOAA/WDS tsunami database is a listing of historical tsunami source events and runup locations throughout the world that range in date from 2000 B.C. to the present. The events were gathered from scientific and scholarly sources, regional and worldwide catalogs, tide gauge data, deep ocean sensor data, individual event reports, and unpublished works. There are currently over 2,000 source events in the database with event validities >0 (-1 = erroneous entry, 0 = seiche). The global distribution of these events is 61% Pacific Ocean, 22% Mediterranean Sea, 7% Atlantic Ocean, 6% Indian Ocean, 4% Caribbean Sea, and 1% Black Sea. There are over 13,000 runup locations where tsunami effects were observed. The global distribution of these locations is 82% Pacific Ocean, 9% Indian Ocean, 4% Mediterranean, 3% Atlantic Ocean, and 2% Caribbean Sea.

In the period 1970-2005, the DB contains information about 96 sure tsunamis (validity = 4: definite tsunami) recorded worldwide with a "Maximum Water Height" (*) >= 1 m. Following NOAA/WDS, how many among them were >= 10 m?

To express your best and confidence interval estimates associated with <u>the number of recorded tsunamis since 1970 with a Maximum Water Height >= 10 m,</u> please provide the 5th, 50th, and 95th percentiles in the following table.

Percentiles:	5th (min)	50th (best guess)	95th (max)
Estimate (num):			

Reference: National Geophysical Data Center / World Data Service (NGDC/WDS): Global Historical Tsunami Database. National Geophysical Data Center, NOAA. doi:10.7289/V5PN93H7; DB search in June 24 2016.

(*) The maximum water height above sea level in meters for this event. If the type of measurement of the runup was a:

- Tide Gauge - half of the maximum height (minus the normal tide) of a tsunami wave recorded at the coast by a tide gauge.
- Runup Height - the maximum elevation the wave reaches at the maximum inundation.

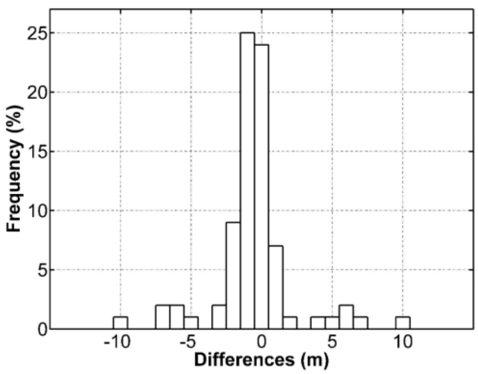
Question 10

Inundation distances on the Sendai Plain during the March 11, 2001 Tohoku tsunami reached up to 5 km from the shoreline (Mori et al. 2011). Lynett (2016) used GEOCLAW and MOST models on a up to 10 m grid for simulations of this tsunami on the Sendai Plain, and compared the results with the observations. Run-up elevations and inundation distances are generally over predicted. The agreement improves for average inundation distances along a profile (see table below) and is better for inundation distances than for run-up elevations. Lynett (2016) reanalysed the observations, removed some points, and interpolated the remaining for estimating an inundation line, finding a run-up distribution with average 1.89 m and standard deviation of 0.70 m. GEOCLAW gives an average of 3.34 m and a standard deviation of 0.37 m. The discrepancies are attributed to errors in the topographic model. Estimated differences between field data run-up heights and the topographic elevations from the numerical grid at the location of the runup measurements are presented in the figure below.

Average inundation distance from field measurements and models.

	MOST model	GeoClaw model	Field data
Avg. (m)	**4460.5**	**4739.3**	**4451.5**
Max. (m)	**6246.4**	**6562.4**	**5947.0**
Min. (m)	**1993.3**	**2746.9**	**2107.3**
Avg. Abs. Diff. (m)*	**525.2**	**644.3**	**N.A.**

**Average absolute difference between field data and model predictions.*



What is the average run-up along the inundation line modelled with MOST by Lynett (2016)?

To express your best guess and confidence interval estimates associated with <u>this average run-up,</u> please provide the 5th, 50th, and 95th percentiles in the following table.

Percentiles:	5th (min)	50th (best guess)	95th (max)
Estimate (yr^{-1}):			

Reference: Lynett P., Simulation Confidence in Tsunami-Driven Overland Flow, PEER Report No. 2016/03 (2016)

Question 11

Synolakis (1991) developed analytical run-up relation for a solitary wave on simple straight beach slope. The amplification of non-breaking waves between the incoming wave before the slope and the final run-up is described by the run-up law, which relates the final scaled run-up height R/d to the initial amplitude before the slope H/d, where d is the water depth before the slope. His analytical result agrees well with experimental results and is also used to validate tsunami inundation models.

For a gentle sloping beach with slope 1:19.85 (2.88°), what is the amplification factor (R/H) for an incoming wave with amplitude of 1m at a depth of 100m?

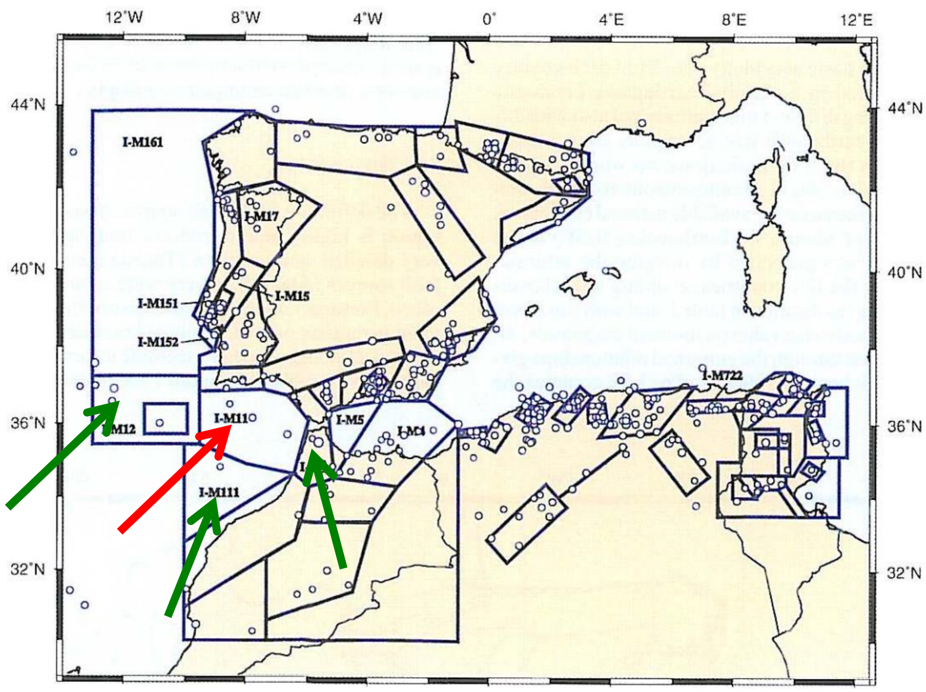
To express your best and confidence interval estimates associated with the amplification factor, please provide the 5^{th}, 50^{th}, and 95^{th} percentiles in the following table.

Percentiles:	5^{th} (min)	50^{th} (best guess)	95^{th} (max)
Estimate (R/H):			

Reference: Synolakis, C. E. (1991). Tsunami runup on steep slopes: How good linear theory really is. Natural Hazards, 4(2), 221–234.

Question 12

Jiménez & García-Fernández (1999) presented the contribution of the Ibero-Maghreb region to the global GSHAP map. In order to homogenize the zonation, sources overlapping at national borders were considered as candidates to be redefined in Jiménez & García-Fernández (1999). The re-evaluated seismicity parameters are based on the available national catalogues (from 1900 to 1989 with moment magnitude >= 4.5). The maximum magnitude Mmax estimated for the source zones I-M9, I-M111, and IM-12, are 5.3, 5.5, 6.6, respectively (green arrows).



Following Jiménez & García-Fernández (1999), which is the maximum magnitude Mmax in the source zone I-M11?

To express your best and confidence interval estimates associated with the Mmax of zone I-M11 provided by Jiménez & García-Fernández (1999), please provide the 5th, 50th, and 95th percentiles in the following table.

Percentiles:	5th (min)	50th (best guess)	95th (max)
Estimate (Mmax):			

Reference: Jiménez MJ, García-Fernández M (1999), Seismic hazard assessment in the Ibero-Maghreb region, Annali di Geofisica 42 (6).

Question 13

The Cascadia subduction zone off western North America is characterized by low seismicity rates, which explains the relatively late recognition of it being a major subduction zone with potential for large tsunamigenic earthquakes. The convergence rate along the margin is on the order of 35 mm/yr. Goldfinger et al. studied the paleoseismic/paleotsunami record along the entire margin and based on the turbidite record postulated a return time for events along the subduction zone.

What is the return time that Goldfinger et al. (2012) found for earthquakes that rupture the entire subduction zone from northern California to British Columbia (900-1,100 km in length)?

To express your best and confidence interval estimates associated with this return period (in years), please provide the 5^{th}, 50^{th}, and 95^{th} percentiles in the following table.

Percentiles:	5^{th} (min)	50^{th} (best guess)	95^{th} (max)
Estimate (yr):			

Reference: Goldfinger, C., Nelson, C. H., More, A. E., Johnson, J. E., Patton, J. R., Karabanov, E., et al. (2012). Turbidite event history—Methods and implications for Holocene paleoseismicity of the Cascadia subduction zone (No. 1661-F). United States Geological Survey Professional Paper (p. 184).

Question 14

In describing the Probabilistic Seismic Hazard Analysis results, UCERF3 (2013) describes hazard curves as it follows: *"A seismic hazard curve gives, for a site, the probability of exceeding various earthquake shaking levels over a specified period of time period (typically 50 years for building codes). The type of shaking is referred to as the ground motion parameter, or intensity measure type, with the most widely used including peak ground acceleration (PGA) and spectral acceleration (SA) at 3-second, 1-Hz, and 5-Hz (3s SA, 1Hz SA, and 5Hz SA, respectively). For example, the seismic design provisions recommended by the Building Seismic Safety Council (2009) use 1Hz and 5Hz SA. To support engineering design and building codes, the USGS NSHMP publishes probabilistic ground motion maps, which show the shaking levels that have a certain probability of being exceeded over a given time period (the hazard-curve x-axis value corresponding to some y-axis level, with the latter typically being the 2-percent- or 10-percent-in-50-years exceedance probability)."*

Assuming a Poisson distribution, to which average return period corresponds an exceedance probability threshold of 2 percent in 50 years?

To express your best and confidence interval estimates associated with the mean return period corresponding to an exceedance probability of 2% in 50 yr, please provide the 5^{th}, 50^{th}, and 95^{th} percentiles in the following table.

Percentiles:	5^{th} (min)	50^{th} (best guess)	95^{th} (max)
Estimate (Pr):			

Reference: The Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3)—The Time-Independent Model, USGS Open-File Report 2013–1165, CGS Special Report 228, Southern California Earthquake Center Publication 1792, http://pubs.usgs.gov/of/2013/1165/pdf/ofr2013-1165.pdf

Acknowledgment-based weighting scheme

Adopting an acknowledgement-based expert scoring scheme, expert opinion is weighted on the basis of mutual recognition among experts expressed through a blind procedure. To quantify such weights, we ask you to vote yourself and two other colleagues within this Panel of Experts, whose members are given in the Table below. **Your votes will be kept secret, except for those of us conducting the experiment.**

For each vote, you can provide a weight either 1 or 3 (not 2!) indicating the strength of the confidence on your colleagues. A weight equal to 3 reflects a greater strength compared to a weight equal to 1.

In order to vote, please follow the **following rules**:

- You must vote for **yourself with weight 1**;
- You must vote **two other colleagues** (neither one, nor three):
    - one colleague with weight 1,
    - one colleague with weight 3.

Please, express your vote by putting a cross (**X**) in the following table.

Expert	WEIGHT 1	WEIGHT 3
F. Romano (INGV)		
R. Omira (INGV)		
F. Lovholt (NGI)		
A. Babeyko (GFZ)		
A. Yalciner (METU)		
G. Papadopoulos (NOA)		
M. Canals (UB)		
INM		
A. Armigliato (UNIBO)		
M. Sorensen (UiB)		
C. Ozer (KOERI)		
G. Davies (GA)		
W. Power (GNS)		
J. Polet (Caltech)		
C. Meletti (INGV)		

Please, check your choice:

- *The total number of crosses should be 3*
- *The sum of weights should be 5*