PRIORITIZATION OF STEPS & LEVELS FOR THE DEVELOPMENT OF ALTERNATIVE MODELS

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Introduction

A diverse range of scientifically acceptable models should be considered for quantifying the epistemic uncertainty in this hazard assessment. The consideration of (in principle) all relevant scientifically acceptable alternative models in the implementation is an essential step in this respect (e.g., Marzocchi et al. 2015; USNRC 2012; SSHAC 1997). It will be important not only to include all "acceptable" models, but also to assign them weights according to their relevancy in the specific application. Then, models and weights will be finally used to quantify the "*informed community distribution*" describing the variability of the results that you would expect if you ask different experts within the technical community to perform the analysis (SSHAC 1997, USNRC 2012).

It is clearly impossible - and maybe not even useful - to implement all the potentially acceptable models at all the levels of the analysis (e.g., Bommer & Scherbaum, 2008). Recall that in TSUMAPS-NEAM we have "discretized" the S-PTHA into 4 STEPs, and then into several levels within each of the STEPs. At each STEP/level several alternatives have been considered for implementation.

In order to reduce the total number of models to be implemented, the "*tree of the alternatives*" should be carefully trimmed, in order to focus the best efforts on the most relevant STEPS, on the most relevant levels, and on the most relevant alternative models; in other words, we need to try to explore in greater detail the choices expected to affect most the final results and the associated uncertainty.

This prioritization is here based on the opinion of the Pool of Experts (PoE), and it is the goal of this questionnaire. The final enumeration of alternatives and the quantification of the weights is the goal of a next questionnaire, foreseen for Dec 2016 / Jan 2017.

The group opinion will be here extracted by considering an Analytical Hierarchy Process (AHP). The AHP is a multi-criterion decision model introduced by Thomas Saaty (1980). The AHP takes as input integer numbers expressing the degree of preference of one model over another, ranging from one (equally important) to nine (extremely more important). These numbers can be seen as the nearest integer to the ratio of the weights assigned to each model.

In this elicitation, we consider the simplest configuration of AHP, by considering simply one criterion for the comparison, that is, your personal belief. **Table 1** exhibits the information about the fundamental scale to be used in AHP for judgments in pairs for this criterion. The scale enables the expert to incorporate experience and knowledge intuitively and indicates how many times a STEP/Level/Sublevel dominates the others with respect to the goal of the assessment. Based on experts' judgments, the final scores (positive numerical values) are generated following the steps of the AHP, determining the score of each level and sublevel.

In the following, we first present an illustrative example of AHP questionnaires, to show how this questionnaire should be answered. Then, the main part of the questionnaire starts. In Question #1, we will ask you to prioritize the computational STEPs of the S-PTHA analysis in TSUMAPS-NEAM project. Then, in Questions #2 to #5, you will be asked to prioritize the levels (and the sublevels) inside each of these STEPs. In each question, you are asked to fill one table.

Please, review the illustrative example provided in the next pages. Then, to express your opinions, a total of 5 tables should be filled: tables Q1, Q2, Q3, Q4, and Q5.

Table 1: Fundamental scale of absolute numbers

Intensity of Importance	Definition	Explanation	Weights of models
1	Equal importance	Two steps/levels/sublevels contribute equally to the objective	0.5-0.5
3	Moderate preference	Experience and judgment slightly favor one step/level/sublevel over another	0.6-0.4 (x1.5)
5	Strong preference	Experience and judgment strongly favor one step/level/sublevel over another	0.75-0.25 (x3)
7	Very strong preference	A step/level/sublevel is favored very strongly over another; its dominance demonstrated in practice	0.95-0.05 (x19)
9	Extreme preference	Overwhelming evidence favoring one step/level/sublevel over another	0.99-0.01 (x99)

Illustrative example of AHP

<u>We provide you</u>: A set of alternatives (say five), as in **Table 2** below.

Table 2: Alternatives to be used for pairwise comparisons.

No.	Model code	Description
1	A1	*Alternative 1*
2	A2	*Alternative 2*
3	A3	*Alternative 3*
4	A4	*Alternative 4*
5	A5	*Alternative 5*

<u>We ask you to provide the relative importance of models in pairs</u>, through a question like: *In your opinion, the alternative in **column A** is either **More important** or **Equal important** or **Less important** than the alternative in **column B** with respect to your personal belief? <u>Please express your opinion by ticking a box with 'X' in each row in **Table 3**</u>. For intensity of importance, please see Table 1.*

Table 3: Pairwise comparisons of alternatives. Red crosses are used to express the expert opinion.

No. of comparisons	**A**	Intensity of importance									**B**
		More important than				Equal	Less importance than				
		9	7	5	3	1	3	5	7	9	
1	A1				X						A2
2	A1							X			A3
3	A1					X					A4
4	A1								X		A5
5	A2				X						A3
6	A2			X							A4
7	A2					X					A5
8	A3			X							A4
9	A3								X		A5
10	A4									X	A5

The choices in table 3 stand for:

i) <u>For the first row</u>, if A1 is **more important** with moderate intensity than A2, then tick the box with '**X**' under 3 on the left side of 1.

ii) <u>For the second row</u>, if A1 is **less important** with strong intensity than A3, then tick the box with '**X**' under 5 on the right side of 1.

iii) <u>For the third now</u>, If A1 is **equally important** to A4, then tick the box with '**X**' under 1.

And so on . . .

References

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Question 1: Prioritization of STEPs

(MOSTLY FROM TSUMAPS-NEAM DOCUMENT #1: OVERVIEW ON THE WORKFLOW FOR THE ASSESSMENT)

The general approach to SPTHA adopted in TSUMAPS-NEAM is defined into the following 4 STEPS:

STEP 1 - PROBABILISTIC EARTHQUAKE MODEL: The goals are 1) the definition of the parameters of all the possible representative seismic sources that may generate tsunamigenic earthquakes in the future and the quantification of their long-run frequency (mean annual rates). This analysis is mostly probabilistic, and it is organized in the following levels:

- Level 0: Regionalization, Definition of the Predominant Seismicity (PS) sources, Seismic DBs.
- Level 1: Magnitude-frequency distribution for each region, defined through the contribution to it of Predominant Seismicity (PS) and Background Seismicity (BS).
- Level 2a: Variability (position on hosting fault and finite size fault area, average slip and slip distribution) of earthquakes of the Predominant Seismicity in each region, given each magnitude. PS sources (from Level 0) are 3D, potentially curved.
- Level 2b: Variability (location, depth, faulting focal mechanism, *finite fault size area, average slip, slip distribution*) of earthquakes of the Background Seismicity in each region, given each magnitude. BS sources are assumed planar.

Predominant Seismicity (PS) Source Definition: Several individual well-known fault structures may be of particular relevance for tsunami generation (e.g., they include larger magnitudes, as for example, subduction interfaces). If such structures are well known (e.g., in their 3D fault properties), the earthquakes occurring in these well known interfaces (hereinafter, Predominant Seismicity - PS) can be treated separately from the rest of the seismicity (hereinafter, Background Seismicity - BS), in order to maximize the use of all the available information on such predominant faults.

Background Seismicity (BS) Source Definition: Since we cannot exclude that earthquakes happen outside known faults, or since we cannot exclude that faults are not mapped well enough everywhere (particularly offshore), we allow the earthquakes to happen everywhere in a volume and with variability of the faulting mechanism. In the present case, the faulting mechanism probability can be constrained by the presence in the same cell of known faults (not treated as PS) or by historical seismicity.

In each region defined by the regionalization, three different situations may happen: 1) a region is treated as a mix of PS and BS (e.g. a subduction zone and the crustal earthquakes above it); a region is treated as pure BS (similarly to some PSHA approaches, in the present case were no really major structures that are mapped well enough are present); a pure PS region (e.g. distant subduction sources, for whom modeling the great earthquakes happening on the known interface is enough, such as the Caribbean sources, which are very distant from the target NEAM coastlines).

STEP 2 - TSUNAMI GENERATION & MODELING IN DEEP WATER: the goals are 1) the simulation of the sea floor displacement, and 2) the simulation of the tsunami generation and propagation from the source to the target area, up to a given bathymetric depth. This analysis is mostly deterministic , and it is organized in the following levels:

- Level 0: Crustal model (elastic parameters, friction); Topo-Bathymetric datasets and digital elevation models
- Level 1: Co-seismic displacement model
- Level 2: Tsunami generation model
- Level 3: Tsunami propagation (in deep water) model

STEP 3 - SHOALING AND INUNDATION: the goals are 1) the simulation of the last phases of the tsunami impact, 2) the stochastic simulation of the associated uncertainty (including uncertainty deriving both from simplified source modeling and simplified tsunami modeling), and 3) the combination of the tsunami with the tides. This analysis is partly deterministic and partly stochastic, and it is organized in the following levels:

- Level 0: Topo-bathymetric datasets and digital elevation models
- Level 1: Amplification and inundation model
- Level 2: Tidal stage model
- Level 3: Uncertainty modeling for tsunami hazard metrics (including stochastic modeling of unmodeled effects from STEPS 1-3, and tides)

STEP 4 - HAZARD AGGREGATION & UNCERTAINTY QUANTIFICATION: the goals are 1) the quantification of the hazard curves at the target sites, and 2) the disaggregation analysis. This analysis is mainly probabilistic, and it is organized in the following levels:

- Level 0: Elicitation of experts, historical tsunami DB, paleotsunami DB
- Level 1: Combination of STEPS from 1-3
- Level 2: Quantification of uncertainty
- Level 3: comparison/test with tsunami records

Each of the STEPs contains a number of quantitative assessments that may potentially introduce epistemic uncertainty on the SPTHA results, as summarized in the following table:

No.	Model code	Description
1	STEP1	Definition of the seismic source variability and quantification of the long-run frequencies of all the seismic sources
2	STEP2	Tsunami generation and off-shore propagation
3	STEP3	Near-shore tsunami propagation and inundation
4	STEP4	Computation of the weights of the alternative models developed in STEPs 1 to 3 to measure their credibility, and construction of the “ensemble” model

In your opinion, the STEP in **column A** is either **More/ Equal / Less important** than the STEP in **column B** in terms to its contribution to the total epistemic uncertainty of the hazard assessment?

<u>Please express your opinion by ticking a box with '**X**' in each row in the following **Table Q1**</u>. For intensity of importance, please see ***Table 1***.

A STEP is to be considered more important than another STEP if the epistemic uncertainty associated to that specific STEP is expected to have more influence on the final results (either because it is larger than that for the other STEP or because its influence on the results is larger than the one of the other STEP). Hence, more alternative models should be developed to carefully explore and quantify this epistemic uncertainty for the STEP that is judged more important. Such alternative models will either be implemented, if this is feasible within the resources allocated to the project; or the need for their implementation in a future assessment will be clearly reported.

Table Q1: Pairwise comparisons of S-PTHA STEPs.

No. of comparisons	A	Intensity of importance									B
		More important than				Equal	Less important than				
		9	7	5	3	1	3	5	7	9	
1	STEP 1										STEP 2
2	STEP 1										STEP 3
3	STEP 1										STEP 4
4	STEP 2										STEP 3
5	STEP 2										STEP 4
6	STEP 3										STEP 4

Question 2: Prioritization of levels and sublevels of STEP 1

(MOSTLY FROM TSUMAPS-NEAM DOCUMENT #2: MORE DETAILED EXPLANATION OF THE "LEVELS" FOR STEP 1)

The main goal at STEP 1 is the definition of a probabilistic model describing the parameter variability of future potentially tsunamigenic seismic sources and the long-term frequency of occurrence of each combination of parameters.

This analysis is organized into an Event Tree (ET) that decomposes the problem into a chain of discrete conditional probabilities for aleatory variables describing the earthquakes.

Each level of the ET is dedicated to one or to a group of parameters. At each level, we discretize the parameter(s) into a finite number of values that the parameter(s) may assume. Then, we develop several methods to quantify the probability of occurrence for each one of these values, conditioned to the previous levels of the Event Tree.

As seen in the previous section, at STEP 1 we have defined 3 levels (0-2).

Level 0, as for the next STEPs, is used for treating the databases (with also possible alternatives) which are relevant for the STEP.

Level 1 quantifies the seismic moment release of each region as the sum of the contribution of Predominant Seismicity (PS) and Background Seismicity (BS).

Level 2 has two branches (2a, 2b), regarding PS and BS respectively. Levels 2a and 2b represent actual Event Trees, which include several sub-levels.

Different methods can be considered at each level, in order to quantify the variability of the assessments depending on the quantification method adopted. Details on potential alternatives are reported in "**APPENDIX A - ALTERNATIVE MODELING AND CRITICAL CHOICES**".

The levels in STEP 1 are qualitatively described in more details below.

- ***Level 0 - Regionalization & Seismic DBs***
  At this level, we discuss the regionalization, the employed/available seismicity and fault databases, and their basic processing techniques (e.g., declustering, determination of completeness).
  The <u>regionalization</u> is a division of the entire source space relevant for the NEAM region into as many as possible homogeneous tectonic regions, based on the dominant style of crustal deformation and the expected prevailing faulting style and the available data regarding the seismic sources in each region.
  <u>Seismic DBs</u> include: seismicity catalogues and their attributes (e.g. completeness levels), moment tensor and focal mechanism catalogues, fault catalogues, geodetic and geologic records and data.

- ***Level 1 - Magnitude-frequency distribution for each region, defined through the contribution to it of Predominant Seismicity (PS) and Background Seismicity (BS)***

  At this level the frequency of the different magnitudes in each region (as defined at Level 0) is quantified as the sum of the contribution of PS and BS. This distribution is proportional to the average (on time) total seismic moment release of the region. *One earthquake belongs to the region if the geometrical center of its fault is inside the region.* The result of level 1 consists of two frequency-size distributions (for PS and BS).
- ***Level 2a - Variability of earthquake of the Predominant Seismicity in the region, given the magnitude***

  At this level, we consider only the earthquakes occurring on the interfaces (namely, the Predominant Seismicity - PS). All the parameters identifying individual sources on the 3D geometry defined at Level 0 are analyzed. The PS analysis is subdivided into 2 sub-levels::
  - SUBLEV. PS-1 - spatial distribution and area: position and size of the rupture area, and average slip, based on scaling laws, are here treated simultaneously.
  - SUBLEV. PS-2 - slip distribution: static or time dependent heterogeneous slip distribution within the rupture area.
- ***Level 2b - Variability of earthquakes of the Background Seismicity - BS)***

  At this level, we consider only the earthquakes occurring outside the interfaces (namely, the Background Seismicity). For BS, the dominant faulting mechanism is not unique. We analyze all the parameters (location, depth, strike, dip, rake, slip) identifying individual sources and we model them as rectangular planar faults. The BS analysis is subdivided into 5 sub-levels:
  - SUBLEV. BS-1 - spatial distribution of earthquakes: given an earthquake of a given magnitude in a given region, the probability that it occurs in a specific cell on a regular grid that covers all the regions; one earthquake belongs to a cell if the geometrical center of its fault is inside the cell.
  - SUBLEV. BS-2 - depth distribution: the probability distribution in each cell of Level BS-1.
  - SUBLEV. BS-3 - focal mechanisms: in principle, all the possible faulting mechanisms and geometries are possible; here, we analyze the probability distribution that each combination occurs in each cell (but, of course, in different proportions according to their expected PDF's, as derived by past seismicity and presence of known faults).
  - SUBLEV. BS-4 - fault sizes: length and width of the rectangular rupture area and its associated average slip for the given earthquake, based on scaling laws.
  - SUBLEV. BS-5 - slip distribution: static or time dependent heterogeneous slip distribution within the faults area.

Within the described levels and sublevels, we enumerated a total of 10 groups of quantitative decisions/assessments that may potentially introduce epistemic uncertainty on the STEP 1 results, as reported in the following table:

No.	Model code	Description
1	Region	Level 0 - Regionalization
2	PSDef	Level 0 - Selection of interfaces to be modeled separately
3	SeismicCat	Level 0 - Seismic catalogues
4	FreqMag	Level 1 - Quantification of the Magnitude-frequency (of PS and BS, separately)
5	PS-Pos	Level 2a - Sublevel PS-1: spatial distribution (position and area) and average slip of earthquakes over PS
6	PS-Slip	Level 2a - Sublevel PS-2: slip distribution of PS
7	BS-Pos	Level 2b - Sublevel BS-1/2: hypocentral distribution of BS
8	BS-Mech	Level 2b - Sublevel BS-3: focal mechanism of BS
9	BS-Size	Level 2b - Sublevel BS-4: size of finite faults of BS (scaling laws)
10	BS-Slip	Level 2b - Sublevel BS-5: slip distribution of BS

In your opinion, the model in **column A** in **Table Q2** is **More important** or **Equally important** or **Less important** than the model in **column B** with respect to the goal of the assessment (quantification of the epistemic uncertainty at this level). Please express your opinion by ticking a box with '**X**' in each row in following **Table Q2**. For intensity of importance, please see *Table 1*.

Table Q2: Pairwise comparisons of the levels and sublevels of STEP 1.

No. of comparisons	A	Intensity of importance									B
		More important than				Equal	Less important than				
		9	7	5	3	1	3	5	7	9	
1	Region										PSDef
2	Region										SeismicCat
3	Region										FreqMag
4	Region										PS-Pos
5	Region										PS-Slip
6	Region										BS-Pos
7	Region										BS-Mech
8	Region										BS-Size
9	Region										BS-Slip
10	PSDef										SeismicCat
11	PSDef										FreqMag
12	PSDef										PS-Pos
13	PSDef										PS-Slip
14	PSDef										BS-Pos
15	PSDef										BS-Mech
16	PSDef										BS-Size
17	PSDef										BS-Slip
18	SeismicCat										FreqMag
19	SeismicCat										PS-Pos
20	SeismicCat										PS-Slip
21	SeismicCat										BS-Pos
22	SeismicCat										BS-Mech
23	SeismicCat										BS-Size
24	SeismicCat										BS-Slip
25	FreqMag										PS-Pos
26	FreqMag										PS-Slip
27	FreqMag										BS-Pos
28	FreqMag										BS-Mech
29	FreqMag										BS-Size
30	FreqMag										BS-Slip
31	PS-Pos										PS-Slip
32	PS-Pos										BS-Pos
33	PS-Pos										BS-Mech
34	PS-Pos										BS-Size
35	PS-Pos										BS-Slip
36	PS-Slip										BS-Pos
37	PS-Slip										BS-Mech
38	PS-Slip										BS-Size
39	PS-Slip										BS-Slip
40	BS-Pos										BS-Mech
41	BS-Pos										BS-Size
42	BS-Pos										BS-Slip
43	BS-Mech										BS-Size
44	BS-Mech										BS-Slip
45	BS-Size										BS-Slip

Question 3: Prioritization of levels and sublevels of STEP 2

(MOSTLY FROM TSUMAPS-NEAM DOCUMENT #2: MORE DETAILED EXPLANATION OF THE "LEVELS" FOR STEP 2)

Once each specific earthquake scenario has been defined with its probability at STEP 1, the process of tsunami generation and propagation in deep water is here numerically modeled. Differently from STEP 1, the modeling approach of STEP 2 deals with the numerical modeling of the phenomenon, and can be entirely deterministic.

The outputs of this step are tsunami waveforms, modeled on a chosen isobath along the coasts of interest at chosen points of interest in front of them.

Different methods can be considered at each level, in order to quantify the variability of the assessments depending on the quantification method adopted. Details on potential alternatives are reported in "**APPENDIX A - ALTERNATIVE MODELING AND CRITICAL CHOICES"**.

The levels in STEP 2 are qualitatively described in more details below.

- **Level 0 - Crustal model (elastic parameters); Topo-Bathymetric datasets and digital elevation models**
  At this level, we discuss the employed/available: crustal models employed for calculation of the displacement; topo-bathymetric databases, and the preparation of the digital elevation model on a grid (the topo-bathymetric grid) used for subsequent tsunami numerical modeling.
- **Level 1 - Coseismic displacement model**
  The (static or dynamic) seafloor displacement is here modeled, according to the input slip distribution obtained at STEP 1.
- **Level 2 - Tsunami generation model**
  This is the step where the tsunami initial condition is derived starting from the seafloor deformation history obtained at the previous level.
- **Level 3 - Tsunami propagation (in deep water) model**
  Here, the offshore points of interest where the hazard has to be evaluated are defined. Then the boundary conditions are set, and the tsunami associated to each earthquake scenario is simulated numerically over the bathymetric grid, according to the initial condition provided at the previous level; the waveforms are extracted at the points of interest.

Within the described levels, we enumerated a total of 5 groups of quantitative decisions/assessments that may potentially introduce epistemic uncertainty on the STEP 2 results, as reported in the following table.

No.	Model code	Description
1	Crust	Level 0 - Crustal models (elastic parameters)
2	TopoBath	Level 0 - Topo-bathymetric datasets and digital elevation models
3	CoSeis	Level 1 - Coseismic displacement model
4	TsuGen	Level 2 - Tsunami generation model
5	TsuProp	Level 3 - Tsunami propagation (in deep water) model

In your opinion, the model in **column A** is either **More important** or **Equal important** or **Less important** than the model in **column B** with respect to the goal of the assessment (quantification of the epistemic uncertainty at this level). Please express your opinion by ticking a box with '**X**' in each row in following **Table Q3**. For intensity of importance, please see *Table 1*.

Table Q3: Pairwise comparisons of the levels of STEP 2.

No. of comparisons	A	Intensity of importance									B
		More important than				Equal	Less important than				
		9	7	5	3	1	3	5	7	9	
1	Crust										TopoBath
2	Crust										CoSeis
3	Crust										TsuGen
4	Crust										TsuProp
5	TopoBath										CoSeis
6	TopoBath										TsuGen
7	TopoBath										TsuProp
8	CoSeis										TsuGen
9	CoSeis										TsuProp
10	TsuGen										TsuProp

Question 4: Prioritization of levels and sublevels of STEP 3

(MOSTLY FROM TSUMAPS-NEAM DOCUMENT #2: MORE DETAILED EXPLANATION OF THE "LEVELS" FOR STEP 3)

STEP 3 concerns the modeling of the tsunami in coastal shallow waters and the inundation process, and of the associated uncertainty - possibly including those propagating, because of numerous simplifications, from STEP 2 and STEP 3.

The outputs of this step are the time histories or the maxima of the chosen hazard metrics (e.g. runup, inundation distance, currents), and their probability distributions, obtained at the chosen points of interest along the coast or inland.

At STEP 3 we have defined 4 levels (0-3). Level 0, as for other STEPS, is used for treating databases (with also possible alternatives) which are relevant for the STEP. Levels 1-2 are the levels describing the deterministic part of the shallow water and coastal tsunami simulation modeling.

As said, as a result of (unavoidable) simplifications in the modeling of the earthquakes and tsunamis, there is the need of treating the resulting uncertainty affecting the hazard intensity estimate. Level 3 then deals with the modeling of the uncertainty of the hazard metric/intensity.

Different methods can be considered at each level, in order to quantify the variability of the assessments depending on the quantification method adopted. Details on potential alternatives are reported in "**APPENDIX A - ALTERNATIVE MODELING AND CRITICAL CHOICES**".

The levels in STEP 3 are qualitatively described in more details below.

- **Level 0 - Topo-bathymetric datasets and digital elevation models**
  At this level, we discuss the employed/available topo-bathymetric databases, and the preparation of the digital elevation model on a grid (the topo-bathymetric grid), or along 1D profiles, used for subsequent inundation numerical modeling.
- **Level 1 - Amplification and inundation model**
  Here, the points of interest along the coast, and inland, corresponding to the offshore points of STEP 2, and where the hazard has to be evaluated are defined. Then the boundary conditions are set, and the tsunami associated to each earthquake scenario is simulated numerically over high resolution grids, or modeled along 1D profiles, according to offshore results provided at the previous level; the waveforms and/or the maxima are extracted at the points of interest.
- **Level 2 - Tidal stage model**
  At level 2 the probability of the tidal stage is evaluated at the points of interest, in order to be combined with the tsunami.
- **Level 3 - Uncertainty modeling for tsunami hazard metrics (including stochastic modeling of unmodeled effects from STEPS 1-3, and tides)**

Here, we model the uncertainty on the tsunami metrics that arise from the actual limitations in the source description of STEP 1, in the generation and propagation in deep water of the tsunami of STEP 2, and in the inundation modeling in the previous levels of STEP 3 (e.g., 1D models based on topo-bathymetric profiles). These uncertainties are here modeled with a Probability Density Function (e.g., a log-normal distribution).

Within the described levels, we enumerated a total of 4 groups of quantitative decisions/assessments that may potentially introduce epistemic uncertainty on the STEP 3 results, as reported in the following table

No.	Model code	Description
1	TopoBath	Level 0 – Topo-bathymetric datasets and digital elevation models
2	Inund	Level 1 – Amplification and inundation model at the points of interest along the coast, and inland, corresponding to the offshore points of STEP 2
3	Tide	Level 2 – Evaluation of the probability of tidal stage at the points of interest
4	Uncertainty	Level 3 - Model the uncertainty on the tsunami metrics

In your opinion, the model in **column A** is either **More important** or **Equal important** or **Less important** than the model in **column B** with respect to the goal of the assessment (quantification of the epistemic uncertainty at this level). <u>Please express your opinion by ticking a box with '**X**' in each row in the following **Table Q4**.</u> For intensity of importance, please see *Table 1*.

Table Q4: Pairwise comparisons of the levels of STEP 3.

No. of comparisons	A	Intensity of importance									B
		More important than				Equal	Less important than				
		9	7	5	3	1	3	5	7	9	
1	TopoBath										Inund
2	TopoBath										Tide
3	TopoBath										Uncertainty
4	Inund										Tide
5	Inund										Uncertainty
6	Tide										Uncertainty

Question 5: Prioritization of levels and sublevels of STEP 4

(MOSTLY FROM TSUMAPS-NEAM DOCUMENT #2: MORE DETAILED EXPLANATION OF THE "LEVELS" FOR STEP 4)

The main goal of STEP 4 is the combination of the outcomes of STEPS 1 to 3 into a single hazard model. Hazard results are produced in the form of hazard curves (exceedance probability curve) over a given time window (exposure time) at each chosen point of interest in the NEAM region.

A different hazard curve is produced for each of the considered alternatives (recall this questionnaire is a first step in the selection of the alternatives to be developed!). A very important and critical point of STEP 4 is the way in which the different alternatives are weighted, and how these weights are computed. The ensemble of the hazard curves is produced from these curves and weights, quantifying the inherent uncertainty. In this way, aleatory and epistemic uncertainty are simultaneously quantified and propagated in all the results. Different statistics (quantiles) of the ensemble are then used to describe the results and the uncertainty.

From the hazard curves, different hazard and probability maps are produced. Hazard curves are also further elaborated to produce ensemble disaggregation analyses.

At STEP 4 we have defined 3 levels (0-2). Level 0 is where the weights of the alternative models are defined. Levels 1-2 are those regarding hazard aggregation and concrete uncertainty treatment, respectively.

Different methods can be considered at each level, in order to quantify the variability of the assessments depending on the quantification method adopted. Details on potential alternatives are reported in "**APPENDIX A - ALTERNATIVE MODELING AND CRITICAL CHOICES**".

The levels in STEP 4 are qualitatively described in more details below.

- **Level 0 - Elicitation of experts**
  At this level, the relative credibility of alternative implementations is quantified by means of weights: this task is made through expert elicitation of the Panel of Experts (PoE).
- **Level 1 - Combination of STEPS 1 to 3**
  At this level, the contribution to the hazard at each target of all the sources are aggregated, considering the mean annual rate of each source (STEP 1), the generation and propagation in deep water of the consequent tsunami (STEP 2) and its inundation (STEP 3). The process is repeated for each alternative model, to evaluate hazard curves, and for disaggregation analyses.
  Level 2 - Quantification of uncertainty
  At this level, all the alternative implementations are weighted and are used as input to specific integration models (e.g., Logic Tree, Ensemble models) to produce, for each target point, a "community distribution" that simultaneously quantifies aleatory and epistemic uncertainty.

Within the described levels, we enumerated a total of 2 groups of quantitative decisions/assessments that may potentially introduce epistemic uncertainty on the STEP 4 results, as reported in the following table**:**

No.	Model code	Description
1	WeightsExperts	Level 0 – Quantification of weights of the experts
2	Aggregation	Level 1 – Method for aggregating hazard results within each model
3	WeightsModels	Level 2 – Quantification of the weights of alternative models
4	EpisIntegration	Level 2 – Method for integrating the alternative models into a single model that quantifies also the epistemic uncertainty (e.g., Logic Tree, Ensemble models)

In your opinion, the model in **column A** is either **More important** or **Equal important** or **Less important** than the model in **column B** with respect to the goal of the assessment (quantification of the epistemic uncertainty at this level). Please express your opinion by ticking a box with '**X**' in each row in the following **Table Q5**. For intensity of importance, please see *Table 1*.

Table Q5.2: Pairwise comparisons of the levels of STEP 4.

No. of comparisons	A	Intensity of importance									B
		More important than				Equal	Less important than				
		9	7	5	3	1	3	5	7	9	
1	WeightsExperts										Aggregation
2	WeightsExperts										WeightsModels
3	WeightsExperts										EpisIntegration
4	Aggregation										WeightsModels
5	Aggregation										EpisIntegration
6	WeightsModels										EpisIntegration

APPENDIX A - ALTERNATIVE MODELING AND CRITICAL CHOICES

(TSUMAPS-NEAM DOCUMENT #3: ALTERNATIVE MODELING AND CRITICAL CHOICES)

In this document, we report a brief list of possible alternatives at each step/level. The goal of this list is to provide an example of what it is meant at each STEP and Level for "alternative models". Some of these alternatives have been considered for implementations in the current framework of TSUMAPS-NEAM, other have been mentioned but discarded (below, labeled as "not planned"). **The final list of implemented alternatives will be defined based on the results of this elicitation experiment, and TSUMAPS-NEAM DOCUMENT #3 will be revised accordingly.**

STEP 1: PROBABILISTIC EARTHQUAKE MODEL

- **Level 0 - Regionalization & Seismic DBs**
  Regionalization: TSUMAPS / SHARE EU FP7
  Seismic catalogues: SHARE+ (completed by TSUMAPS in zones not covered by SHARE)
  Completeness analysis: statistical; historical.
  Declustering: declustered (different methods); not declustered
  Fault catalogues: SHARE
  Past earthquake geometry catalogues: focal mechanism catalogues (CMT, RCMT); earthquake faults (Emma).
  Geodetic rates: Bird's-like method (ASTARTE; Progetto Abruzzo).
  Geologic rates: SHARE.
  3D geometry for Predominant Seismicity (PS):
  Mediterranean: Calabrian Arc, Hellenic Arc, Cyprus Arc
  Atlantic: Gloria fault, Mid-Atlantic Ridge, Caribbean Subduction

  Note 1: Alternatives in catalogues imply alternative assessments at several of the following levels, whenever mentioned

- **Level 1 - Magnitude-frequency distribution**

  Two main alternatives: Joint PS+BS; independent PS+BS. PS and BS distributions may be quantified jointly (mutually dependent) or separately (independent).

  Joint PS+BS: Frequency-Size distribution + separation;

  - FS Distribution:
    - Distribution Shape: GR; Truncated Pareto (including Kijko's method) / Tapered Pareto.
    - Max mag: seismic catalogues; expert judgment.
    - b-value: seismic catalogues; expert judgment.
    - Seismic rate: seismic catalogues declustered / not declustered.
    - Estimation of parameters: Bayesian; MLE (*not planned*).
  - Separation:
    - Shape: functional form and/or magnitude limits (under discussion)
    - Estimation of the parameters: Bayesian, MLE (not planned)
    - Background ratio IS/BS: seismic catalogues with buffer of 5;10;15 km around PS sources.

  Independent PS+BS: separated Frequency-Size

  - PS F-S distribution: GAR approach to FS based on convergence rate
  - BS F-S distribution: as above considering on catalogues of separation; other data (?).

Note 1: Here we should maybe mention the fact that, for the sake of feasibility, some regions include ONLY prevalent seismicity (since we assume they actually dominate seismicity, like the mid oceanic ridge, or far enough from the target coasts, like Caribbean). Moreover, for the same feasibility reasons, the whole NEA region cannot be entirely covered by background seismicity, i.e. the probability of occurrence of earthquakes is assumed to be negligible in some places.

- **Level 2a - Variability of earthquakes in Predominant Seismicity – PS**
  Spatial distribution (SUBLEV PS-1): proportional to slip rate; uniform on crustal regions; uniform on interface (not planned).
  Fault size and average slip (SUBLEV PS-1): scaling law by Strasser; Blaser; Murotani (not planned), other (not planned)
  Slip distribution (SUBLEV PS-2): uniform; heterogeneous; depth dependent (under discussion, involving magnitude-to-slip-renormalization for alternative constant or depth-dependent rigidity); asperity (not planned), segmentation (not planned).

- **Level 2b - Variability of earthquakes in Background Seismicity - BS**
  Spatial distribution (SUBLEV BS-1): uniform; smoothed seismicity Nearest Neighbour; smoothed seismicity adaptive kernel based on seismic catalogues
  Depth distribution (SUBLEV BS-2): uniform; depth-dependent (not planned).
  Focal mechanism (SUBLEV BS-3): fault catalogues, past earthquake geometry catalogues through a Bayesian method; mean mechanism per cell (not planned).
  Fault size and average slip (SUBLEV BS-4): scaling law by Wells & Coppersmith; other scaling laws (not planned).
  Slip distribution (SUBLEV BS-5): uniform; heterogeneous (not planned); depth dependent (not planned).

  Note 1: Definition of where BS in the Atlantic follows several criteria, including: distance from the coast; neglecting seismicity in the oceanic crust far from the coast basing on global earthquake rates assessment; feasibility of tsunami unit source simulations.

STEP 2: TSUNAMI GENERATION & MODELING IN DEEP WATER

- **Level 0 - Crustal model (elastic parameters, friction); Topo-Bathymetric datasets and digital elevation models**
  Crustal model: Poisson solid; regional/local homogeneous and heterogeneous crustal models (not planned).
  Topo-bathymetry: SRTM30+, improved in the NE region with local data, and in the Black Sea with SRTM15+ resampled at 30 arcsec; alternative topo-bathymetric models (not planned).

- **Level 1 - Coseismic displacement model**

<u>Surface/sea floor deformation:</u> Analytical (Okada, Meade); kinematic rupture models involving heterogeneous elastic parameters (e.g. FK, FEM, not planned).

- **Level 2 - Tsunami generation model**
  <u>Tsunami generation:</u> Kajiura low-pass filtering; non 1D non hydrostatic models (not planned); coupled models (level 1+ level 2, not planned).

- **Level 3 - Tsunami propagation (in deep water) model**
  <u>Points of interest:</u> roughly each 10 km / 20 km along the 50 m isobath; sampling at different depths, at different points of interest (not planned).
  <u>Boundary Conditions:</u> open boundary+moving boundary at the coast; sponge layers (not planned); vertical wall at the coast (not planned);
  <u>Propagation model:</u> gaussian shaped unit sources + HySEA NLSW (up to 50m); other approaches such as not using unit sources (i.e. not assuming linearity, not planned); other SW models or other equations such as Boussinesq or Navier Stokes (not planned); other choices concerning the discretization of the problem as time and spatial steps (not planned); size and spacing of the unit sources (not planned).

  Note 1: a disaggregation step somewhere around here might be added (filters to select scenarios for inundation modeling, even if this is a non-planned alternative; see docs #1 and #2)

STEP 3: SHOALING AND INUNDATION

- **Level 0 - Topo-bathymetric datasets and digital elevation models**
  <u>Topo-bathymetry:</u> SRTM30+, local data (check with IPMA), SRTM15+; GEBCO, ASTER, etc. (not planned).
  <u>Digital elevation models:</u> SRTM30+, improved in the NE region with local data, and in the Black Sea with SRTM15+ resampled at 30 arcsec; other local high resolution DEMS, etc. (not planned).

- **Level 1 - Amplification and inundation model**
  <u>Amplification:</u> Locally defined amplification factors (1D profiles) along ~20km separate points [Computes maximum inundation height (MIH) somewhere inland. Mean value bathymetric profiles for sections of stretches. Plane wave assumption for both islands and the mainland. Alongshore moving averaging to remove run-up “spikes”]; high resolution modeling of shoaling, … (not planned); alternative closed form formulas for run-up from tsunami literature (not planned).
  <u>Optional, inundation distance:</u> Combine, topography, coastal dissipation factors, and maximum shoreline water elevation to compute a local inundation distance. Alternatively, produce maps by employing GIS inverse distance weighting extrapolation combining the above information with the STRM30+ topographical map; high resolution inundation models (not planned).

Optional, inundation distance: Uncertainty quantification: Run a limited set of detailed inundation simulations to sample local uncertainty to topography, focussing, inundation flow and dissipation etc. Aggregate with GA/GAR/AECOM uncertainty values.

- **Level 2 - Tidal stage model**
  Tide model: TPXO tool - Tidal signal prediction at TSUMAPS-NEAM receivers (Points of Interest); other models (e.g. NAO99, ..) (not planned); empirical tides (not planned).
  Probability of the Tidal Stage Model: PDF of the predicted tidal signal for each Point of Interest.

- **Level 3 - Uncertainty modeling for tsunami hazard metrics (including stochastic modeling of unmodeled effects from STEPS 1-3, and tides)**
  For Runup: log-normal distribution, with estimation of bias and variance, convolving all the effects (including source and empirical runup variability, tides); address upper bounds for log-normal distribution (not planned); uncertainty from numerical modeling (under discussion); self-consistent modeling of tides and tsunami (not planned).
  Combining PDF of Tidal Stage with tsunami metrics: method TBD (e.g., Mofjeld 2007 approach, Pattern method by Adams et al., 2014, …)

STEP 4: HAZARD AGGREGATION & UNCERTAINTY QUANTIFICATION

- **Level 0:**
  Weights of experts in elicitation: equal weights; performance-based weights (Cooke's method); acknowledgement-based weights (Selva et al. 2012, J Applied Volcanol).
  Tsunami DB: paleotsunami catalog; historical tsunami catalog (To be used for Sanity check on the results - whole STEP 4; however, sanity checks will be performed at all STEPS 1-4 and at all levels within each STEP).

- **Level 1 - Combination of STEPS 1 to 3**
  Exposure time (assumed stationarity of estimations): 50 yr.
  Mean Return Period limits: up to $1x10^5$ yr .
  Combination model (aleatory uncertainty): Poisson model + discretized hazard integral (Lorito et al. 2015; Selva et al. 2016); different choices regarding the discretization of the parameters in the discretized hazard integral (not planned); hazard integral (not planned); time-dependent models (not planned); given MRP (not planned); Scenario Based (not planned).

- **Level 2 - Quantification of uncertainty**
  Weights of alternatives: Expert Elicitation; subjective weights, based on discussions (not planned); Bayesian weights (not planned).
  Integration model: Ensemble modeling; Logic Tree (not planned).