African Seismological Commission (AfSC) - Asian Seismological Commission (ASC)

Preparatory Joint Working Group on Neo-Deterministic Seismic Hazard Assessment (pJWG NDSHA)

Newsletters

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More reliable physics in seismic hazard assessment (SHA) for disaster risk reduction (DRR)

(More reliable physics in SHA for DRR)

This issue

NDSHA helps earthquake early warning (EEW)

Implementation of effective Earthquake Early Warning System (EEWS) may contribute protecting lives and properties. In a paper published this year, it is shown that integrating information provided by physically sound, reliable seismic hazard assessment (NDSHA) can significantly improve performances of current EEWS. Specifically, in this study it is demonstrated that EEWS empowered by NDSHA allows reducing the size of 'blind zone', which is one of the challenges affecting performance of these systems. The paper suggests a practical approach, exploiting information from time-dependent seismic hazard assessment to indicate when and where the number of stations should be temporarily increased. Accordingly, when in a region a temporary increase of seismic hazard is declared, the corresponding ground shaking scenarios provided by NDSHA are used to optimally select, based on costs/benefits analysis, the sites where additional stations should be deployed, in such a way that the 'blind zone' could be temporarily reduced. The work ultimately demonstrates how basic studies in earthquake science, including studies on the physics of seismic waves propagation and the knowledge of the Earth interior, could contribute directly to the engineering endeavor towards reduction of seismic disaster risk.

Y. Zhang, Z. Wu, F. Romanelli, F. Vaccari, A. Peresan, J. Li and G. F. Panza, 2023. Earthquake Early Warning System (EEWS) empowered by Time-Dependent Neo-Deterministic Seismic Hazard Assessment (TD-NDSHA). *Terra Nova*, 35, 230-239. DOI: 10.1111/ter.12647.

The M_{design}

M_{design} is an important issue in SHA (Rugarli et al. 2019). As commented by Prof. Giuliano Panza, most of the data about earthquake size is based on macroseismic Intensity. Reliable magnitude estimates are limited to the last 150 years or so. The existence of many different macroseismic Intensity scales is a demonstration of the complexity of the problem of describing earthquake effects. The multiplicity of scales generates some problems in practical applications, that must therefore rely upon very conservative assumptions. Caution is necessary since many magnitude scales exists, as well. The magnitude value given for a single event is a mathematical result (usually average of different estimations) with very limited physical meaning. This justifies the common use in catalogues to omit error for single event estimations, but makes it compulsory to consider what is estimated at global level, accounting for different reporting agencies (different catalogues). Generally, error in magnitude determination at global scale is about 1/4 (Båth, 1973; Bormann et al. 2007). ΔM_W =1/4 is consistent with the variation that may affect the seismic moment, M_0, as determined, for the same event, by different agencies and methods (e.g., Panza and Saraò, 2000; Saraò et al., 2001; Guidarelli and Panza, 2006; Chu et al., 2009; Rugarli et al. 2019). M_{design} can be defined accounting for error in magnitude determination at global level, not only for recorded events, but also for each potentially discovered seismogenic node (Gelfand, et al., 1972; 1976). In this way M_{design} represents, in each study area, the maximum physically possible magnitude of the scenario event consistent with both the observed magnitude values and those estimated by pattern recognition. Therefore, M_{design} can be considered a formal definition of the maximum credible earthquake (MCE) magnitude. The implementation of M_{design} makes it possible to promptly update existing seismic hazard maps if, within standard errors, the defined M_{design} value is exceeded.

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Deadly earthquakes of 2023

"Earthquakes don't kill people, buildings do!"

The first of the recent 06 February 2023 earthquakes in Turkey of magnitude M_W7.8 occurred at 01:17 UTC followed by the M_W7.5 event at 10:24:48 UTC with epicentres located at 27 km E of Nurdağı and at 4 km SSE of Ekinözü (Turkey), respectively. This Kahramanmaras earthquake sequence (Dal Zilio and Ampuero, 2023) resulted in widespread damage in an area of about 350,000 km^2 and about sixty thousands of fatalities in Turkey and Syria; both earthquakes share tied the 5-6th deadliest quake since 2000 (Table 1). Different agencies reported the extreme macroseismic intensity up to XII (in MMI scale) around the first major shock epicentre and in Antakya, as well the maximum peak ground acceleration (PGA) of 2.2 g recorded at Pazarcık Belediyesi Park and some higher magnitude determinations of the two major earthquakes, e.g. GEOSCOPE estimated M_W8.0 and 7.7 and Geological Survey of Russian Academy of Science provided M_S8.0 and 7.8, respectively, with I_0 = XI-XII in MMI scale for both shocks (which is by no means a fractional part of the qualitative assessment of ground shaking, but reflects the natural uncertainty in determining macroseismic class) . The observed ground shaking was much larger than the maximum PGA estimates with 10% probability of exceedance in 50 years at their sites of either the Global Seismic Hazard Assessment Program (GSHAP, 1999) or Global Earthquake Model (GEM, 2018) final hazard maps. On the other hand, the occurrence of devastating earthquakes was expected in the disjunctive D-node of the morphostructural zonation of Anatolia pattern recognized by Gelfand et al. in 1973 and 1974 (Figure 1) and within the only two out of 262 circles of investigation that spread over most of the global seismic belts where Time of Increased Probability starting from July 2021 was determined in the on-going real-time Global Testing of the M8 algorithm (Healy et al., 1992; Ismail-Zadeh and Kossobokov, 2021; Kossobokov and Soloviev, 2021) aimed at magnitude range M8.0+ (Figure 2) and confirmed in the next semi-annual updates, most recently in January 2023.

The September 8th, 2023, M6.8 - 54 km WSW of Oukaïmedene, Morocco, resulted in widespread destruction in the Marrakech-Safi region and the death of at least 2,946 people. According to measurements at 452 stations, the maximums are I_0 = IX and PGA = 1.23g (https://earthquake.usgs.gov/earthquakes/eventpage/us7000kufc/shakemap/stations), which is 9 times larger than on the latest GEM's map (Pagani et al., 2018). Ground shaking intensity VI was felt at distances of up to 300 km from epicenter.

The four strong M6.3 on October 7th, 11th, and 15th in northwestern Afghanistan caused the death toll of at least 2,445 fatalities according to the Taliban official release as of the 10th of October (while the United Nations reported 1,294 deaths on the same date); eventually the death toll raised after the third and the fourth M6.3 earthquakes located nearer to the city of Herāt (pop. 574,300) than the earlier destructive shocks of October 7th. The ground shaking effects are in agreement with GEM and GSHAP, while showing that the exceedance (so-called, "10% poe in 50 years") does not wait for 50 years and may repeat in an hour or less, as it did happen on October 7th at 06:41:03 and 07:12:50 (UTC). Apparently, we evidence a swarm of M6+ earthquakes in the western Afghanistan, which occurrences in the past have been forerunners for a few cases of the great M8+ earthquakes (Kossobokov and Shebalin, 2003).

TABLE 1. Top deadliest earthquakes since 2000. Notes: at least 1,000+ fatalities including victims of tsunami and other associated effects. The ratio $\boldsymbol{R_{PGA} = mPGA_{GEM}/mPGA_{GSHAP}}$ (* from GEM interactive map); increments $\boldsymbol{\Delta I_0} = I_{0\ EVENT} - I_{0\ GSHAP}$ and $\boldsymbol{\Delta I_0'} = I_{0\ EVENT} - I_{0\ GEM}$ are computed as in (Kossobokov and Nekrasova, 2011; 2012) rounded to the closest integer.

Region	Date	M	Fatalities	ΔI_0	$\Delta I_0'$	R_{PGA}
Sumatra-Andaman Islands	26 Dec 2004	9.0	227,898	4	4	1.20*
Port-au-Prince (Haiti)	12 Jan 2010	7.3	222,570	2	1	3.10
Wenchuan (Sichuan, China)	12 May 2008	8.1	87,587	3	3	1.60
Kashmir (northern border	8 Oct 2005	7.7	87,351	2	2	2.06
Nurdağı (Turkey)	**6 Feb 2023**	**7.8(8.0)**	**59,359+**	**1(2)**	**2**	**1.08**
Ekinözü (Turkey)		**7.5(7.7)**		**1(2)**	**2**	**1.11**
Bam (Iran)	26 Dec 2003	6.6	26,271	0	1	0.86
Bhuj (Gujarat, India)	26 Jan 2001	8.0	20,085	3	2	2.30
Off the Pacific coast of Tōhoku	11Mar 2011	9.0	19,759+	3	3	1.22*
Bharatpur (Nepal)	25 Apr 2015	7.8	8,964	2	2	1.01
Yogyakarta (Java, Indonesia)	26 May 2006	6.3	5,782	0	0	1.57
Sulawesi Island (Indonesia)	28 Sep 2018	7.5	4,340	2	2	1.62
Southern Qinghai (China)	13 Apr 2010	7.0	2,968	2	1	1.68
Oukaïmedene (Morocco)	**8 Sep 2023**	**6.8**	**2,946+**	**3**	**2**	**2.09**
Zindah Jān (Afghanistan)	**7 Oct 2023**	**6.3, 6.3**	**2,445 ?**	**0**	**0**	**1.22**
Boumerdes (Algeria)	21 May 2003	6.8	2,266	2	0	3.75
Nippes (Haiti)	14 Aug 2021	7.2	2,248	2	1	3.39
Nias Island (Indonesia)	28 Mar 2005	8.6	1,313	3	3	2.22
Padang (Southern Sumatra,	30 Sep 2009	7.5	1,117	1	1	1.38
Hindu Kush (Afghanistan)	25 Mar 2002	6.1	1,000+	−1	−1	0.74
Herāt (Afghanistan)	**11, 15 Oct 2023**	**6.3**	**1000+**	**0**	**0**	**1.22**

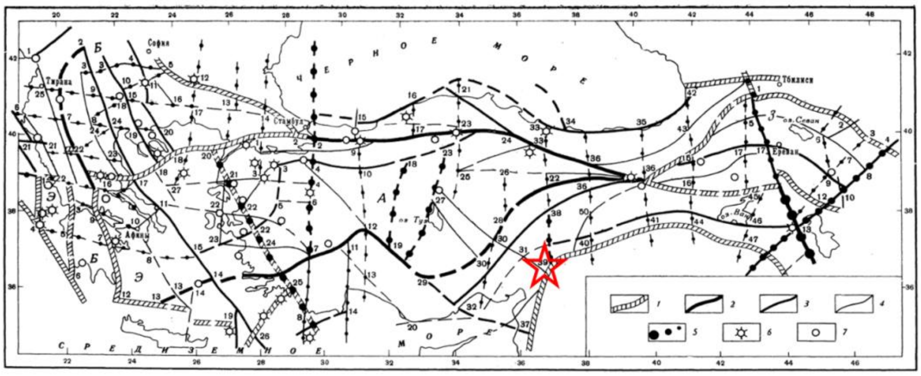

Рис. 1. Морфоструктурная схема Юго-Восточной Европы и Малой Азии. 1—5 — морфоструктурные границы (1—4 — продольные, 5 — поперечные к простиранию основных форм рельефа): 1 — регионов; 2 — морфоструктурных стран; 3 — областей; 4 — районов. 6—7 — эпицентры сильных землетрясений с магнитудой $6{,}5 \leqslant M \leqslant 6{,}9$ (7), $M \geqslant 7$ (6); цифры — номера дизъюнктивных узлов

Figure 1. Morphostructural scheme after (Gelfand et al., 1973) and the epicenter of the 06 February 2023 major main shock (red star).

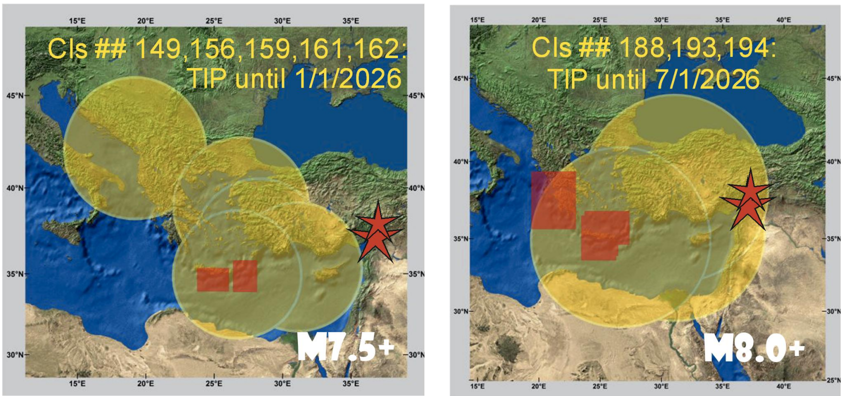

Figure 2. Global Test the M8-MSc predictions: Time of Increased Probability (TIP) diagnostics in Circles of Investigation (CIs) according to M8 algorithm for January–June 2023 and epicenters of the two major shocks of the 2023 Kahramanmaras earthquake sequence (stars). Notes: (1) Forecasts refer exclusively to seismically active areas within 180 and 262 CI's with a radius of 427 and 667 km, focused on global monitoring of the occurrence of the M7.5+ and M8.0+ events, respectively. (2) Both earthquakes occurred outside the territory of the 180 CI's for monitoring in the M7.5+ range (left) and within the cluster of three out of 262 CI's alerted for TIP of M8.0+ earthquake (right). (3) Erroneous refinement of forecasts using the MSc algorithm (Kossobokov et al., 1990) (red polygons) is due to the incompleteness of the catalog of earthquakes in the M4+ range used in the Global Test.

After the deadly 2010 Haiti earthquake, a systematic comparison of the Global Seismic Hazard Assessment Program (GSHAP) final map of the maximum PGA estimates with 10% probability of exceedance in 50 years (10% poe in 50 years) at the sites of actual earthquakes disclosed gross inadequacy of this "probabilistic" product (Kossobokov, 2010); for 50% of 1320 strong (M≥6.0) earthquakes, the PGA values on the GSHAP PGA map were surpassed by 0.17 g or more within 10 years of publication in (Giardini, 1999), which fact evidently contradicts the predicted 10% poe in 50 years. After the 2011 mega-earthquake off the Pacific coast of Tōhoku (Japan) a comprehensive analysis have shown that inadequacy of their final map could have been discovered by the participants of GSHAP based on the earthquake statistics for the period of 1990–1999 (Kossobokov & Nekrasova, 2011; 2012). A decade ago Wyss et al. (2012) have shown "that earthquake mitigation measures in areas where large earthquakes are possible may not be based on GSHAP maps" and urged "that the international project Global Earthquake Model (http://www.globalquakemodel.org/) is on the wrong track, if it continues to base seismic risk estimates on the standard method to assess seismic hazard". Apparently, the contributors to GEM keep misleading interested parties by providing erroneous seismic hazard maps (Pagani et al., 2018). It should be noted, however, that, as a matter of fact, the GEM's Disclaimer does characterize the Model as absolutely useless:

> "The information included in this map must not be used for the design of earthquake-resistant structures or to support any important decision involving human life, capital and movable and immovable properties."

On the contrary, the achieved statistics of testing the term-less predictions (for decades) of the "dangerous" D-nodes and/or D-intersections of the regional schemes of morphostructures [Gorshkov and Novikova, 2018], as well as the intermediate-term middle-range diagnoses of the Times of Increased Probability (for years and a few sources of target earthquakes) for the occurrence of the largest earthquakes worldwide (Ismail-Zadeh and Kossobokov, 2021; Kossobokov and Soloviev, 2021) confirm the evident reliability and usefulness of the pattern recognition approach in step-by-step resolving the issues of operational earthquake forecasting (Kossobokov et al., 2015). It is notable that D-node A39 where the catastrophic earthquakes occurred on February 6, 2023 was characterized already in 1973 by 10 out of 11 class D ("dangerous") features in the absence of those of class N ("not dangerous") transferred from Central Asia to Anatolia and adjacent regions (Gelfand et al., 1973). In Anatolia, features of D-nodes are formed mainly from indicators of tectonic fragmentation of the Earth's crust: the length of the main lineament, the complexity of the node, the proximity of lineaments of the first rank, and the closeness of lineaments.

The last three columns in Table 1 show up the differences between the macroseismic intensity at epicenter of the observed earthquake (I_0 EVENT) and that predicted by the GSHAP and GEM Maps (I_0 GSHAP and I_0 GEM) followed by the ratio RPGA between the predicted maximum PGA values with 10% poe in 50 years on the GEM versus GSHAP maps. Most of the macroseismic intensity differences, sampled by deadliest earthquakes of the 21st century, are positive with their average and median of 2 units on MMI scale, which underestimation of 2 or more units of MMI corresponds, at best, to a transition from STRONG (VI MMI) – light damage to poorly constructed buildings, cracks and a few instances of fallen plaster occur – to SEVERE (VIII MMI) – moderate or heavy damage to ordinary substantial buildings with partial collapse, large cracks in the walls, falling cornices and chimneys.

The values of RPGA (in the last column of Table 1) indicate an apparent upgrade of the GEM Seismic Hazard map in respect to the one of GSHAP; the sampled values with the average of 1.7 and median of 1.6 disclose a tendency to increase maximum PGA values with 10% poe in 50 years at the sites of the occurred (in our case, deadliest) earthquakes. Interestingly, in comparison to GSHAP the seismic hazard at sites of the 2003 Bam and 2002 Hindu Kush earthquakes is downgraded by 14% and 26%, respectively, while is about the same at locations of the 2015 Nepal and 2023 Kahramanmaras earthquakes.

It deserves mentioning that GEM's map appears to ignore ground shaking resulted by many earthquakes with epicenters off shore, including the 26 December 2004 Indian Ocean Disaster and the 11 March 2011 Great Tōhoku earthquake and tsunami; as a matter of fact, only six out of 24 magnitude 8 or larger earthquakes since the year 2000 have GEM's determination of PGA nearby their epicenters.

Evidently, a comprehensive analysis similar to (Kossobokov and Nekrasova, 2012; Wyss et al., 2012) is needed to confirm that, same as GSHAP, the GEM poe product's "inconsistency is inadmissible for any type of responsible evaluation of seismic risk and making decisions concerning earthquake disaster prevention". An indirect confirmation of this claim is the GEM's Disclaimer cited above.

It deserves noting that the "standard method" of Probabilistic Seismic Hazard Analysis of GSHAP and GEM is challenged by methodology of Neo-Deterministic Seismic Hazard Assessment (Panza et al., 2021). This new multi-disciplinary scenario- and physics-based approach for evaluation of seismic hazard that takes advantage of the results of pattern recognition of earthquake prone areas and intermediate-term earthquake prediction of different spatial accuracy, which are tested to be reliable, realistic, and useful evaluation and mapping of apparently time-dependent seismic hazard and associated risks.

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JWG Library (3)

To facilitate the exchange and discussion within the JWG, some of the newsletters will be attaching an important paper for the group to study. In this issue, we attach the paper 'NDSHA: a new paradigm for reliable seismic hazard assessment' by G. F., Panza and J. Bela published in *Engineering Geology* (2020) 275, 105403, DOI 10.1016/j.enggeo.2019.105403. If you have any paper recommended, please contact us.

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