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Reply on RC2

Mariana Belferman et al.

Author comment on "Identifying plausible historical scenarios for coupled lake level and seismicity rate changes: the case for the Dead Sea during the last 2 millennia" by Mariana Belferman et al., Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2021-62-AC2, 2021

- *This paper by Belferman et al. analyzes the correlation between the historical record of lake levels at the Dead Sea and regional seismicity through a numerical simulation of earthquake catalogs. The numerical simulations are based on relating the seismic stress release to characteristic water level curves derived from known control points, or dates of confirmed water levels (with associated uncertainties). The authors find a high correlation between the water level changes and historical earthquake recurrence interval. Overall, the paper is well written and lays out the appropriate motivation for this study. A couple comments are presented below.*
- *As I understand, the assumption is that all stress release occurs along a single purely strike-slip fault plane. The authors acknowledge this assumption in the Discussion, and perhaps this paper is the groundwork for future modeling, but this is quite important.*

We thank the reviewer for addressing two important points, both related to stress release. We will elaborate on these points in discussion in our revised manuscript.

Comment 1:

- *The distribution of smaller magnitude historical events will never be known, however using reasonable expected aftershock decay curves, one could include this additional accumulated stress release from the aftershocks in the modeling, or at least provide as a back-of-the-envelope calculation to determine its significance.*

Response:

Large earthquakes are indeed accompanied by aftershocks, hence some of the stress is released by them. Nevertheless, the crustal response to the earthquake by aftershocks is minor and secondary compared to aseismic creep, as noted for many large earthquakes (e.g. Scholz 1972).

This holds also for the Dead Sea Transform: following the last large earthquake (7.2 Mw) that occurred in 1995 along the southern part of the plate boundary, the aftershocks continued for about two years (Fig. 1). At least 50 percent of the total moment associated with these aftershocks was released during the first day after the main shock and over 95 percent in the first 3 months (Baer 2008). In total, the moment released by post-seismic deformation in the period of 6 months to 2 yr after the Nuweiba earthquake is about 15 percent of the co-seismic moment release (Baer 2008).

In the time scale presented in our study, when the minimal inter-seismic period is about 50 years, the stress released during post-seismic period of 2 years can be considered a part of the main shock. This is further justified when considering the time-step we chose for the lake level curve 10 years (please see pp.5 row 105)

Comment 2:

- *Secondly, the purely strike slip fault motion is likely an oversimplification of the stress release. As these events result from over-pressurized fault zones the slip distribution likely has non-double-couple components. While the total stress released is governed by the seismic moment, the length and orientation of the principal stress vectors relative to the expected shear stress can be significant for a range of plausible fault plane solutions. The modeling for this is not within scope, however my suggestion is to include some more comments regarding the strike-slip assumption.*

Response:

The reviewer correctly states that this aspect is beyond the scope of our research, as are other co-seismic aspects. However, we feel that our assumption regarding the strike slip orientation of the faulting process and sensitivity to the water level changes is well founded.

The far-field maximal and minimal principal stresses, in the Dead Sea region are horizontal (Hofstetter et al., 2007; Palano et al. 2013), which is compatible with the nature of the strike-slip faulting (Anderson, 1951).

The tectonic motion at the DSF is characterized predominantly by left-lateral strike-slip regime with a velocity of ~5 mm/yr along various segments (Garfunkel, 2014; Masson et al.,2015; Sadeh et al., 2012). Large earthquakes that initiate clusters are likely to rupture along the straight ~100 km segments (Lyakhovsky et al., 2001). The strike of these segments parallels to the differential plate velocity vector and thus can be approximated by simple shear.

However, it should be added that due to a pull-apart basin structure of DST, it is possible that a significant part of the stress is released during motion along normal faults. For example, some of the major aftershocks and the slip resulted from 1995 earthquake, was along Gulf-parallel normal faulting NW of the main rupture (Baer 2008). In the Dead Sea Basin, GPS surveys indicate dominance of strike slip loading. Hamiel et al. (2018) show that, on a plate scale, horizontal shear loading dominates the velocity north of the lake. Hamiel and Piatibratova (2019) detected a sub mm/yr component of extension across the southern normal fault bounding the Dead Sea pull apart, yet the strike-slip component across this very fault seems much larger.

Nevertheless, the seismic activity induced by the surface water level fluctuations and affected by the faulting regime is determined in turn by the relative orientations of the three principal stresses (Anderson, 1951). In regions where the vertical compressive stress is not minimal (normal and strike-slip faulting), seismic activity is more sensitive to the effective stress change due to water level change, than in regions where it is minimal (thrust faulting) (Simpson, 1976; Snow, 1982; Roeloffs, 1988). This is applicable to a case of reservoirs approximated as “infinite” in horizontal plane (e.g. Wang, 2000), with respect to the fault zone thickness and location. Such approximation is valid for our study area where the Dead Sea is large enough in a horizontal plane compared to the thickness of the underlying strike-slip fault located in the central part of the valley.

These factors contribute to the high correlation observed between water level changes and historical earthquake recurrence interval.

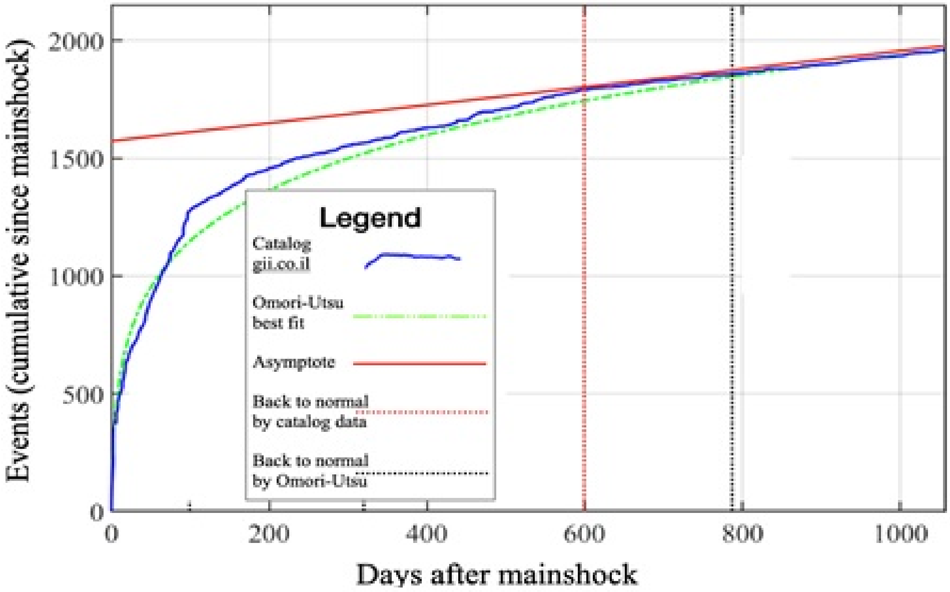

Figure 1: A cumulative count of aftershock ($M_d \geq 2.4$) following the Mw7.2 Gulf of Aqaba earthquake (22/11/1995). The termination of the series is estimated by the departure of the asymptote from the data or the fit to an Omori-Utsu behavior. Agnon et al., 2021

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