Supplement material for Enhanced view of the M_w 6.4 Petrinja (Croatia) earthquake sequence (2020–2022) using deep learning

Dinko Šindija * † [1,2], **Marija Mustać Brčić** [1], **György Hetényi** [3], **Josip Stipčević** [1]

[1]Department of Geophysics, University of Zagreb, Zagreb, Croatia, [2]Institute of Earth Sciences, University of Lausanne, Lausanne, Switzerland

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S1. MLE fitting procedure for Omori–Utsu law

Parameters of the Omori–Utsu law The temporal decay of aftershock activity was analysed using the Omori–Utsu law (Utsu et al., 1995), also referred to as the modified Omori law:

$$n(t) = \frac{K}{(t+c)^p} \tag{1}$$

(Equation 2 in the main text) were estimated by maximising the log-likelihood of the observed event times under the assumption that aftershocks follow a non-homogeneous Poisson process with intensity $\lambda(t) = K(t+c)^{-p}$ (Ogata, 1983). Equivalently, the negative log-likelihood was minimised:

$$-\ln \mathcal{L} = -\sum_{i=1}^{n} \ln \lambda(t_i) + \int_{t_{\mathrm{cut}}}^{T} \lambda(t)\,\mathrm{d}t \tag{2}$$

where t_i are the observed event times, t_{cut} is the post-mainshock incompleteness cutoff, and T is the end of the observation window. This formulation operates directly on unbinned event times, avoiding the information loss and implicit Gaussian error assumption inherent in least-squares fitting to binned or windowed rates.

The incompleteness cutoff t_{cut} was determined objectively via a sensitivity sweep over $t_{\mathrm{cut}} \in [0.00, 0.30]$ days in steps of 0.01 days. At each step, MLE was applied to events with $t > t_{\mathrm{cut}}$ and the fitted parameters K, c, and p were recorded. The optimal t_{cut} was identified as the smallest value at which c stabilises and stops to respond to further increases in the cutoff — the point at which the post-mainshock incompleteness window has been fully excluded. This approach is data-driven and avoids imposing an arbitrary threshold. Notably, for $M_c = 1.1$ = 1.1 the value of c obtained from an unconstrained fit ($t_{\mathrm{cut}} = 0$) closely matches the optimal cutoff identified by the sweep, providing independent confirmation that non-zero c in unconstrained fits reflects incompleteness rather than a physical delay in aftershock onset.

All optimisations used a multi-start Nelder–Mead algorithm with four initial parameter vectors to avoid local minima, retaining the solution with the lowest negative log-likelihood.

References

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*Corresponding author: d.sindija@uea.ac.uk
†Now at the University of East Anglia, United Kingdom