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Unraveling the spatiotemporal fault activation in a complex fault system: the run-up to the 2023 MW 7.8 Kahramanmaraş earthquake, Türkiye

Earthquakes are assumed to be unpredictable, but their forecasting may improve if signatures of preparatory processes can be reliably identified through continuous monitoring. Recent results suggest that years to months before large earthquakes, progressive rock weakening can lead to seismicity localization and coalescence, facilitating fault rupture. If this holds generally, comprehensive, years-long analyses of seismicity may help detect transients signaling proximity to large failure. We test this hypothesis by considering the 2023, Mw 7.8 Kahramanmaraş, Türkiye, earthquake as a case study. A previous study identified an 8-month long activation of seismicity clusters in a complex fault network within 50 km of the future epicenter. To track earthquake evolution at higher resolution, we developed an enhanced seismic catalog combining deep-learning and classic techniques for the six years preceding the mainshock. Recurrent seismicity on the Narlı Fault, a secondary fault where the mainshock nucleated before propagating onto the major East Anatolian Fault Zone intensified months before the event, exhibiting increased localization and interaction. Moreover, in the weeks preceding the mainshock, seismicity surged on a previously quiescent branch aligning with the future rupture plane, yet no immediate foreshocks were observed in the final hours. We propose that persistent damage-induced weakening near the nucleation region primed the system for failure, ultimately enabling rupture propagation toward the main fault. Our findings underscore the importance of long-term, and consistent high-resolution seismic monitoring and analysis for tracking spatiotemporal seismicity transients that may serve as indicators of proximity to rupture.

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