



Supplement of

Integrating smartrock and seismic monitoring to investigate bedload transport dynamics during rapid increase of stages in ephemeral streams

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The grain size distribution (Fig S1) was determined using the Wolman pebble count method, with 100 random selections at 1-meter intervals along the river segment located near the seismometer. The count was performed once, prior to the first event documented in this study.

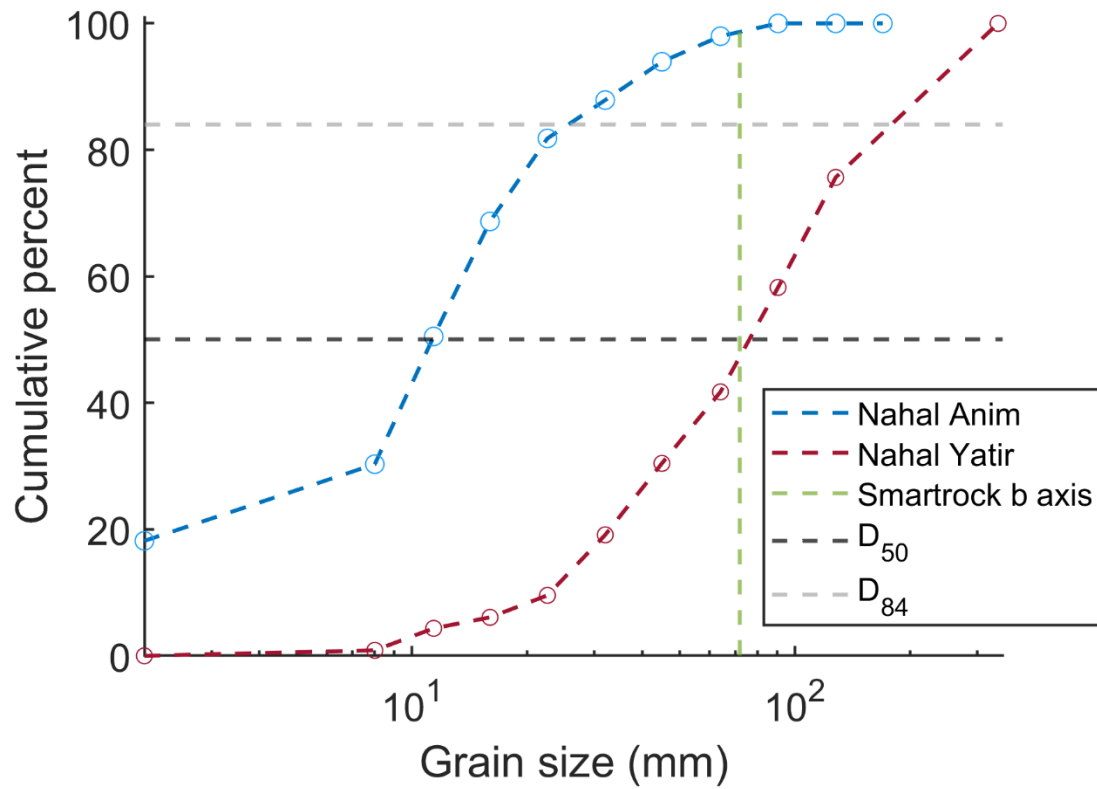


Figure S1. Grain size distribution of Nahal Anim (blue) and Nahal Yatir (red). Dashed lines represent the smartrock b axis size (green), the d_{50} (black) and d_{84} (gray).

S2 Computation the rate of stage rises

We quantified water level rise rates using two methods. The general rise rate was calculated as the slope of a linear regression fitted to all data points during the rise period. The 'maximum rise rate' was determined from the steepest three consecutive data points, representing the most rapid increase in water depth. The maximum duration of rise rate, depends on the sampling rate; it represents 1.5 min during the 2022-23 season and 6 min during the 2021-2022 season. The temporal bounds of each rapid rise event were identified manually based on the hydrograph curvature, with the onset marked at the transition to concave-up and the end point at the transition to concave-down. Figure S2 presents an example of a rapid water level rise, illustrating the distinction between these two methods.

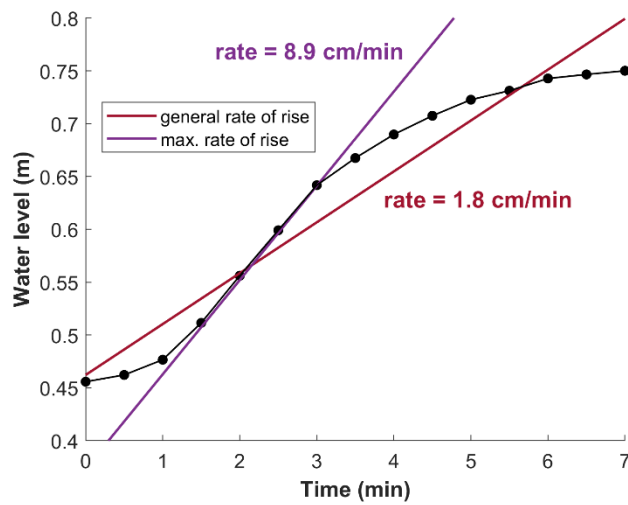


Figure S2. General and maximum rates of rise, event 4 rise 6 (Yatir, February 8 2023).

S3 Time series of rapid stage rises

For all rapid increases of stage mentioned in the main text, the following figures (Fig. S3 – Fig. S7) provide a detailed representation of flow depth, seismic energy, and gyro velocity data.

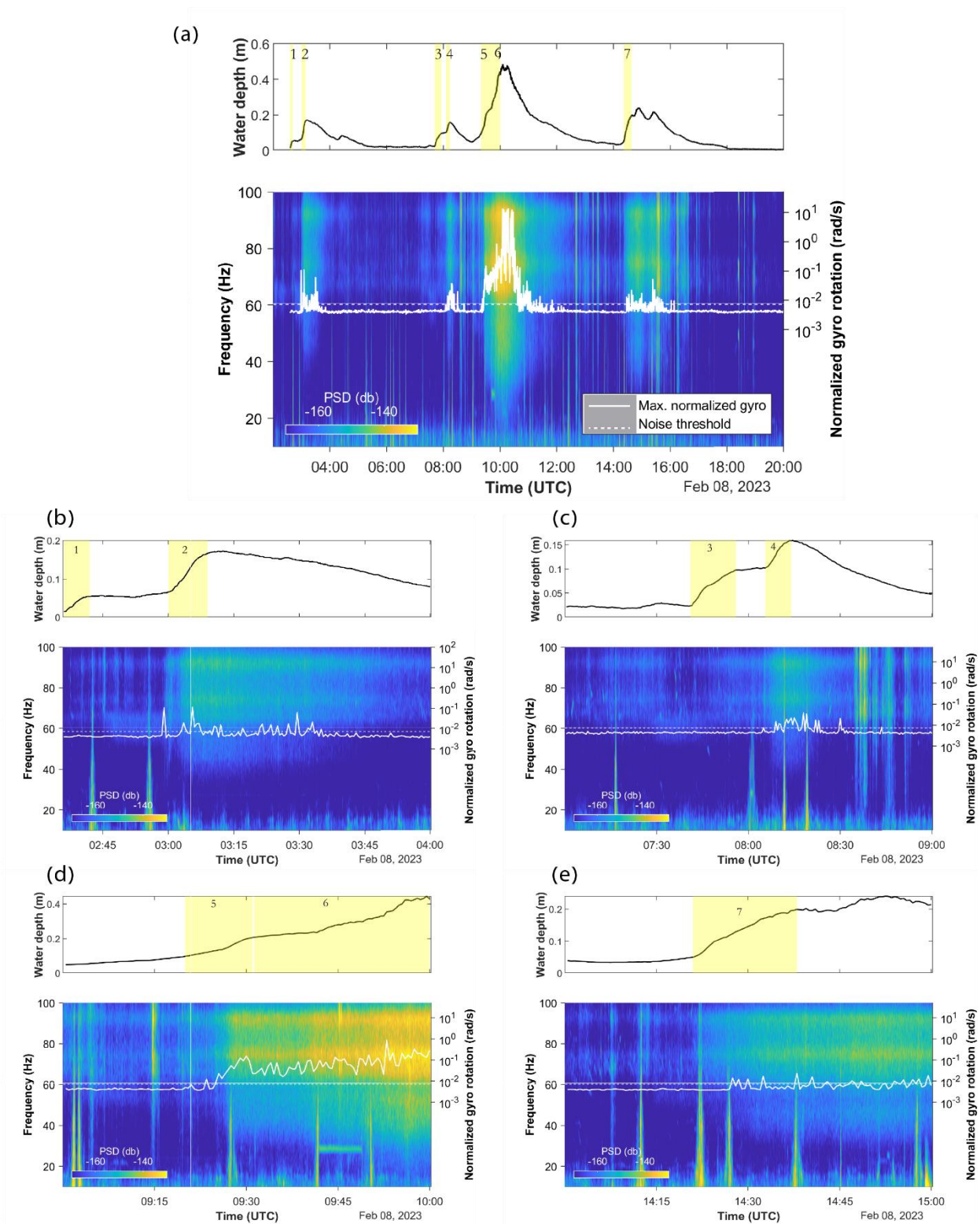


Figure S3. Nahal Anim February 8, 2023 flood event. (a) Data for the entire flood event; (b-e) Data corresponding to periods of rapid water level rise. In each figure the upper panel displays the water stage hydrograph; the lower panels present spectrograms (left y-axis) and particle gyroscopic rotation, shown as a white line (right y-axis). The yellow-shaded areas indicate intervals of rapid water level rise.

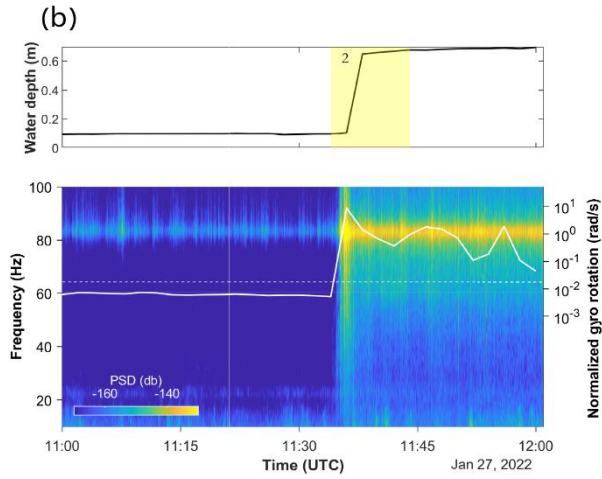
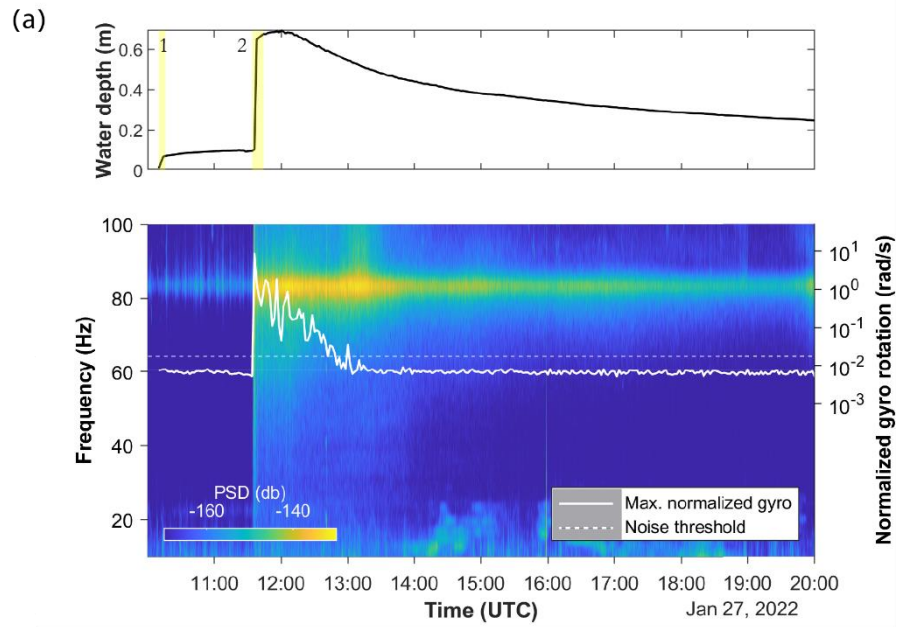


Figure S4. Nahal Yatir January 27, 2022 flood event. (a) Data for the entire flood event; (b) Data corresponding to periods of rapid water level rise. The upper panels display the water stage hydrograph; the lower panel present spectrograms (left y-axis) and particle gyroscopic rotation, shown as a white line (right y-axis). The yellow-shaded areas indicate intervals of rapid water level rise.

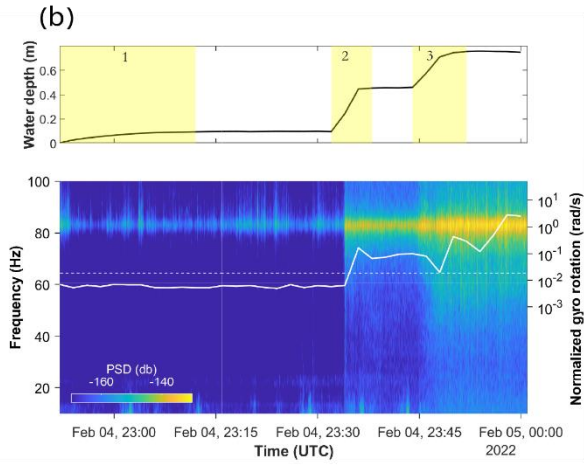
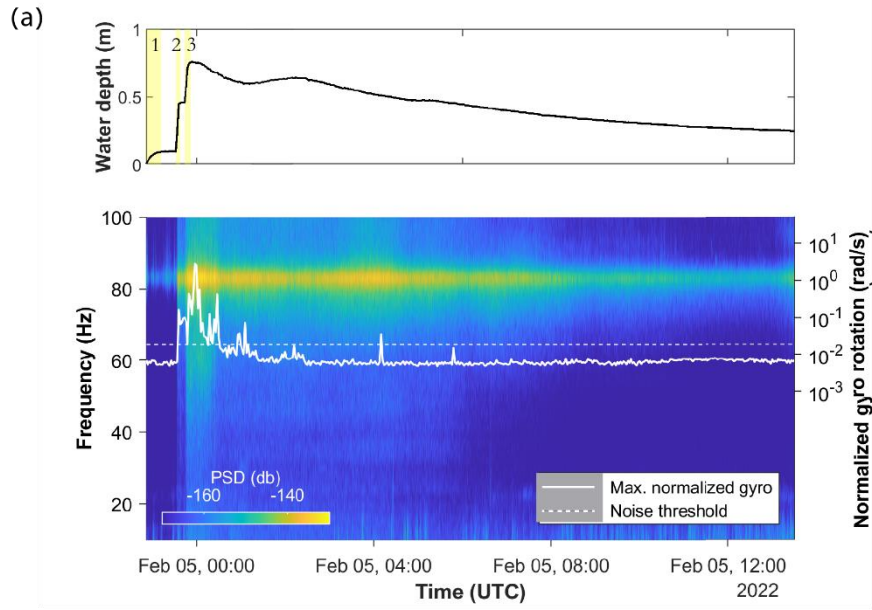


Figure S5. Nahal Yatir February 4, 2022 flood event. (a) Data for the entire flood event; (b-c) Data corresponding to periods of rapid water level rise. The upper panels display the water level hydrograph; the lower panels present spectrograms (left y-axis) and particle gyroscopic rotation, shown as a white line (right y-axis). The yellow-shaded areas indicate intervals of rapid water level rise.

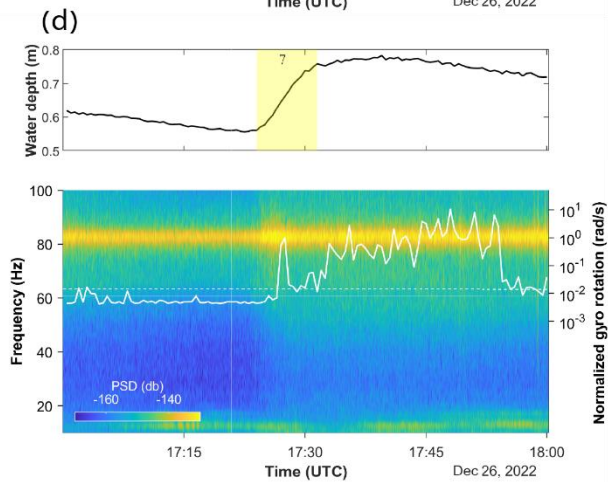
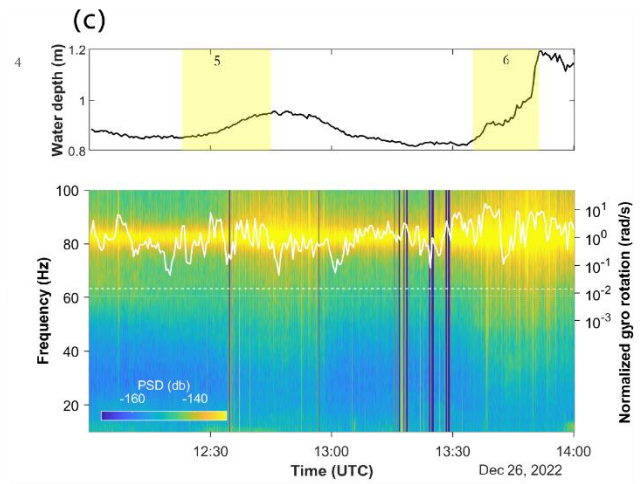
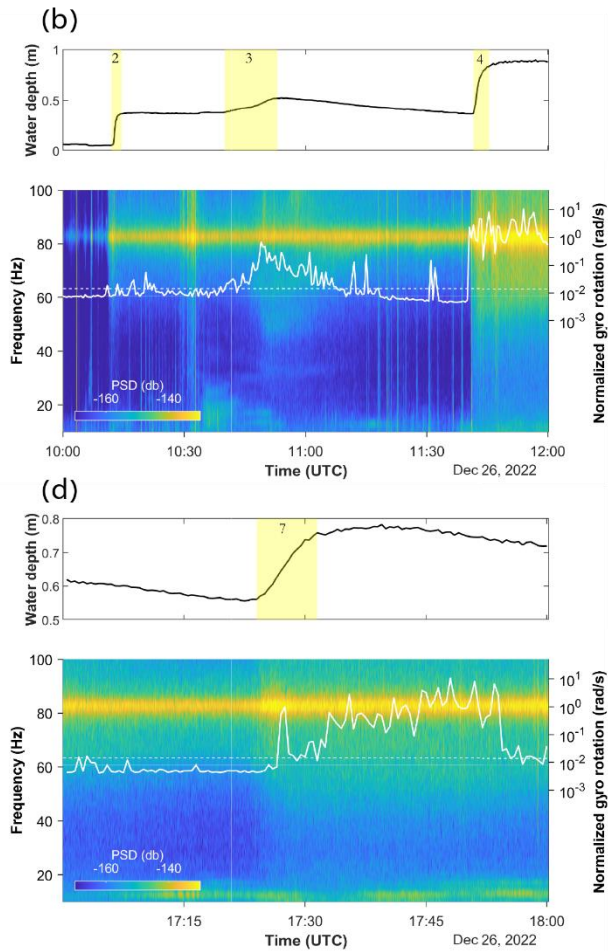
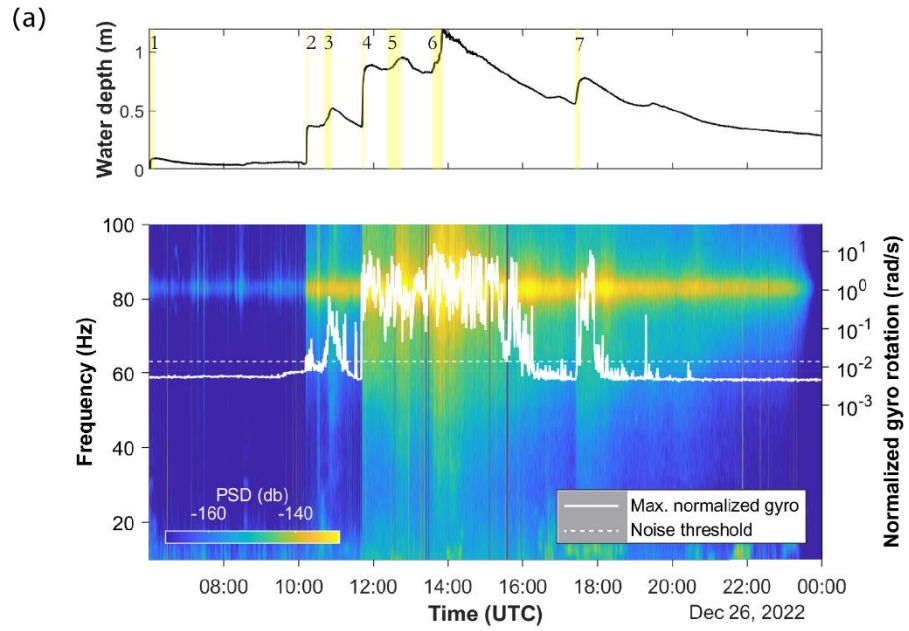


Figure S6. Nahal Yatir December 26, 2022 flood event. (a) Data for the entire flood event; (b-d) Data corresponding to periods of rapid water level rise. The upper panels displays the water level hydrograph; the lower panels present spectrograms (left y-axis) and particle gyroscopic rotation, shown as a white line (right y-axis). The yellow-shaded areas indicate intervals of rapid water level rise.

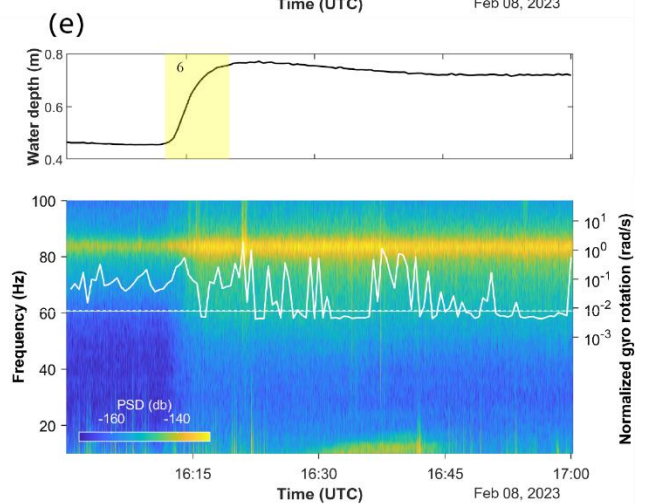
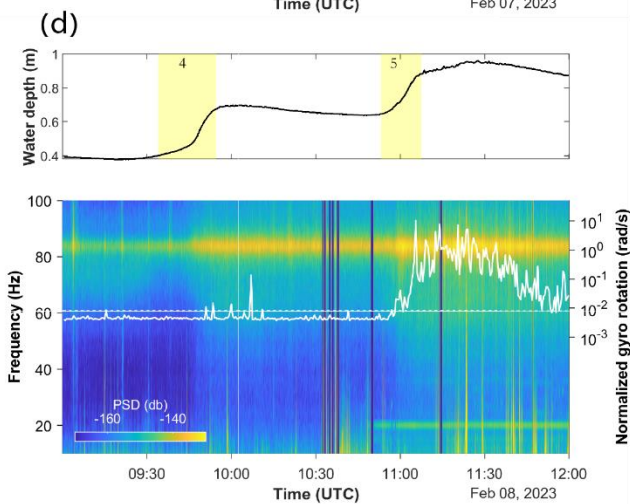
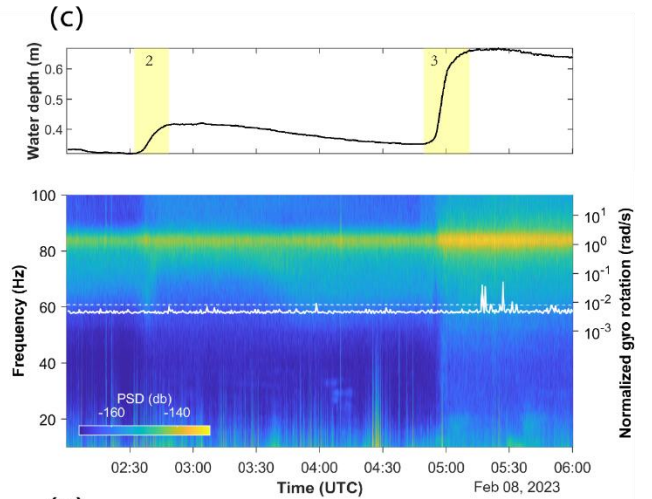
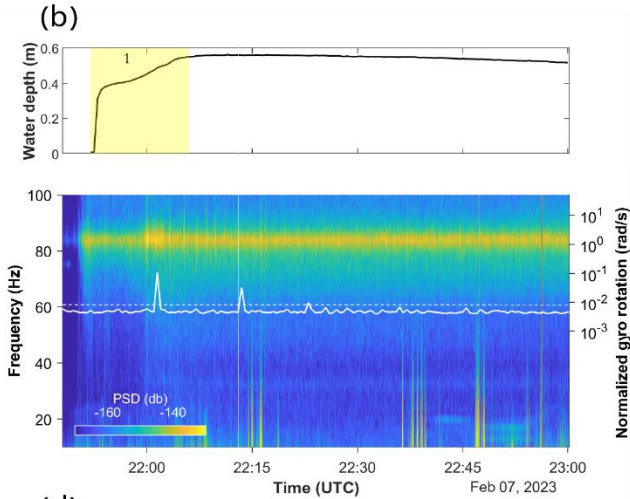
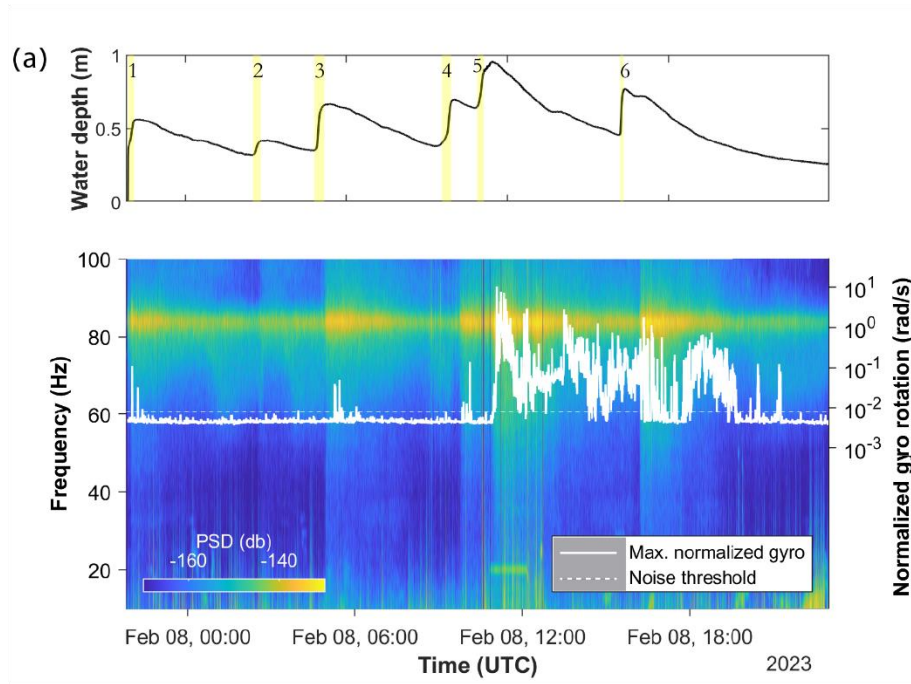


Figure S7. Nahal Yatir February 8, 2023 flood event. (a) Data for the entire flood event; (b-e) Data corresponding to periods of rapid water level rise. The upper panels display the water level hydrograph; the lower panels present spectrograms (left y-axis) and particle gyroscopic rotation, shown as a white line (right y-axis). The yellow-shaded areas indicate intervals of rapid water level rise.

S4 Variation of gyro velocity with water level

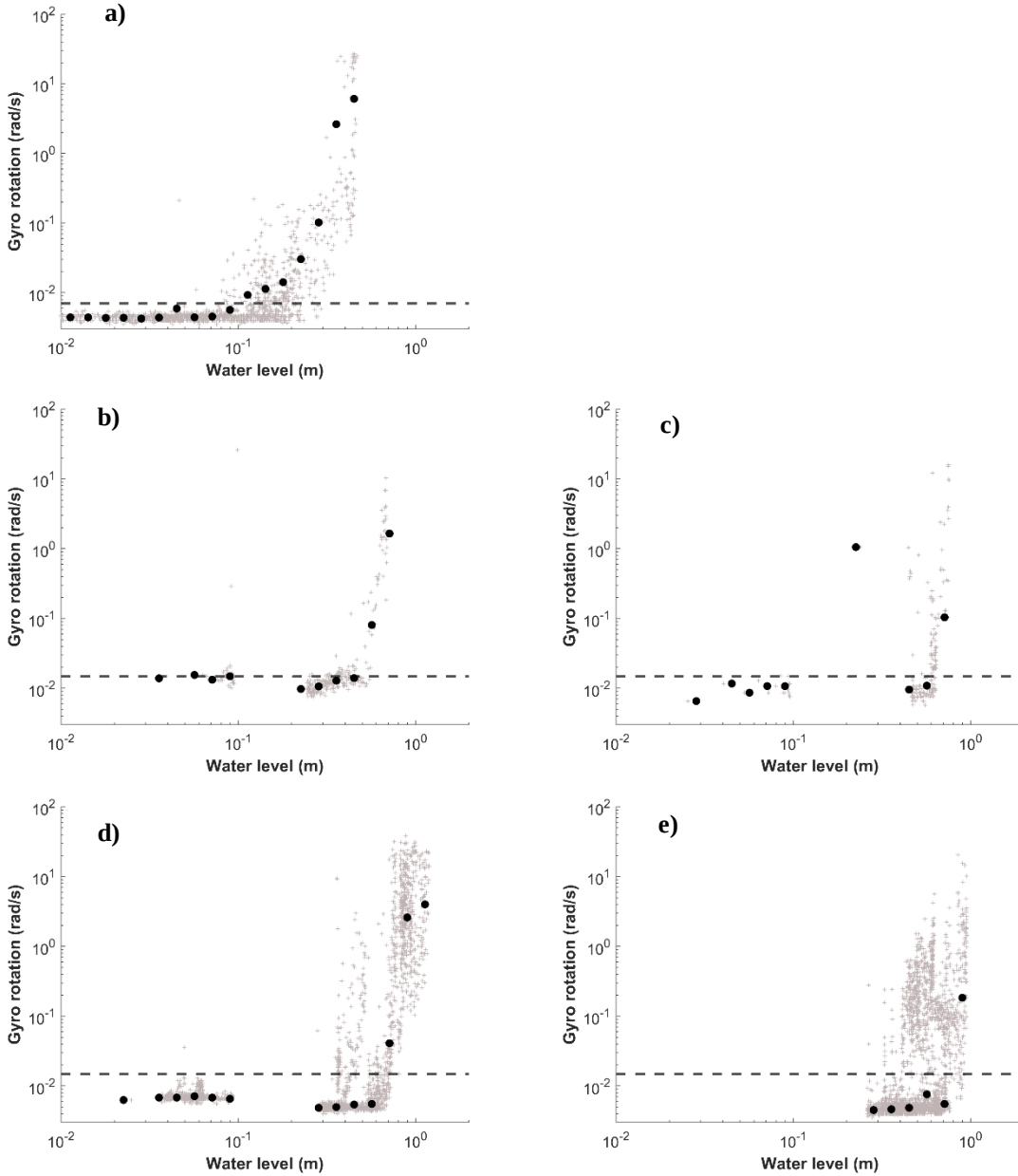


Figure S8. Gyro velocities of smartrocks plotted against water level: (a) Nahal Anim flow event and (b–e) Events 1–4 in Nahal Yatir. The small gray crosses represent all recorded data, while black dots indicate the median values for each water depth bin. The dashed black line denotes the gyro velocity threshold of rest-vibration.

S5 Variation of seismic energy with gyro velocity

For velocities above the noise threshold, a general upward trend in seismic energy is observed, though the pattern varies between events. In the A1, Y1 and Y3 events (Fig. S9a, S9b and S9d), seismic energy increased initially with gyro velocity but became more moderate at higher velocities. In the Y2 event (Fig. S9c) the increase in seismic energy was gradual throughout most of the velocity range above the threshold. In the Y4 event (Fig. S9e) a sharp rise in seismic energy occurred as gyro velocity transitioned from 1 to 2 rad s^{-1} .

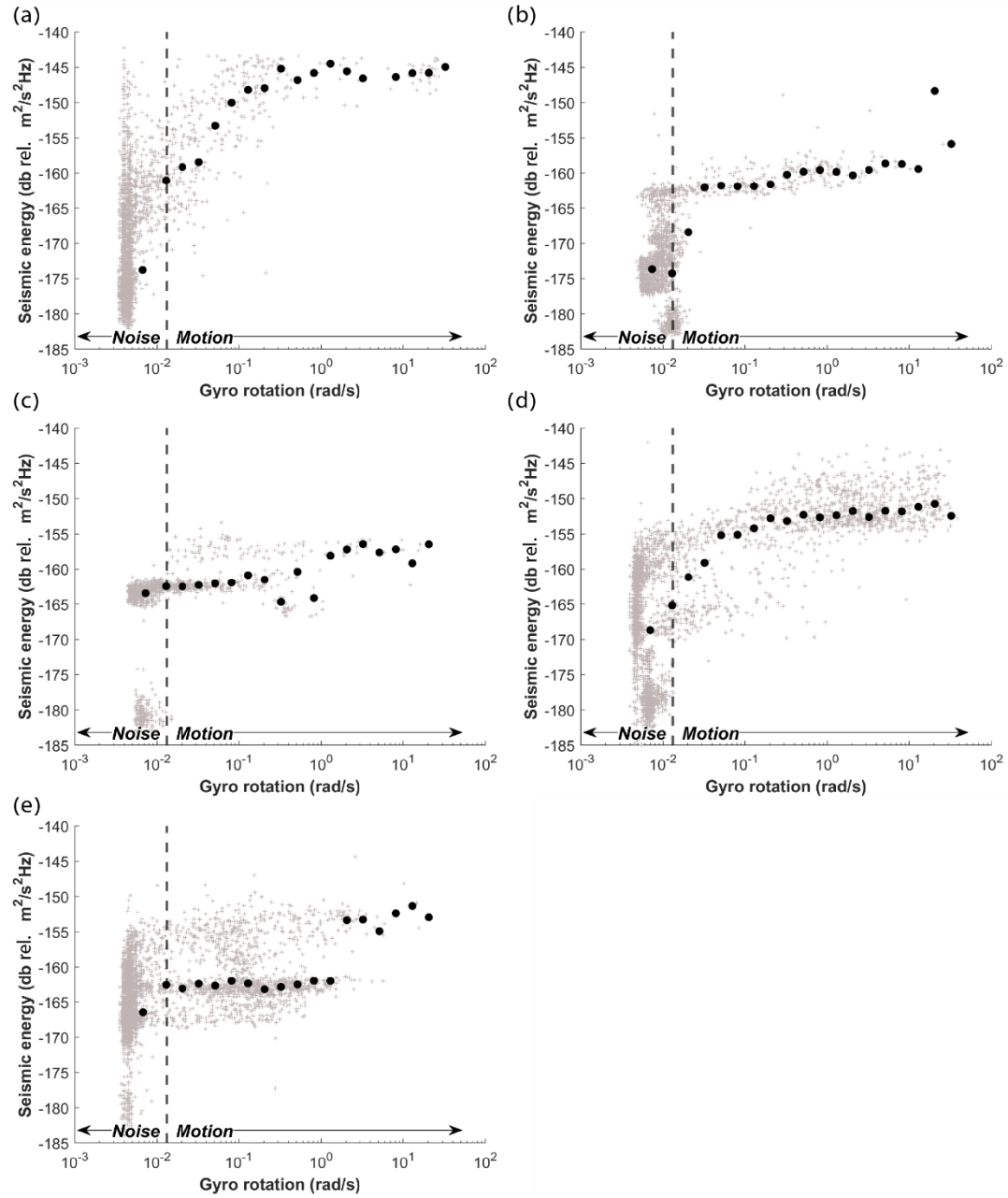


Figure S9. Variation of PSD with gyro velocity; in all events, gray pluses and black dots represent all data and binned data, respectively. (a) Nahal Anim flow event and (b–e) Events 1–4 in Nahal Yatir. Motion refers to vibrations or downstream displacement.

S6 Threshold of gyro vibration-displacement

In Al-Obaidi & Valyrakis (2021) the instrumented particle was positioned within a flume and allowed to move until reaching a fixed pin on the flume bed, from which it returned to its initial position. Particle displacement was measured using both IMU data recorded at 100 Hz and video recordings. While they did not provide an explicit distance threshold for vibration, they presented an example case with a displacement of 0.14 mm. As shown in Fig. S10, at angular velocities of $\sim 0.07 - 0.3 \text{ rad s}^{-1}$, the

particle exhibited minor movement while remaining below the full entrainment threshold. We interpret this range as representing the vibrational phase preceding particle displacement

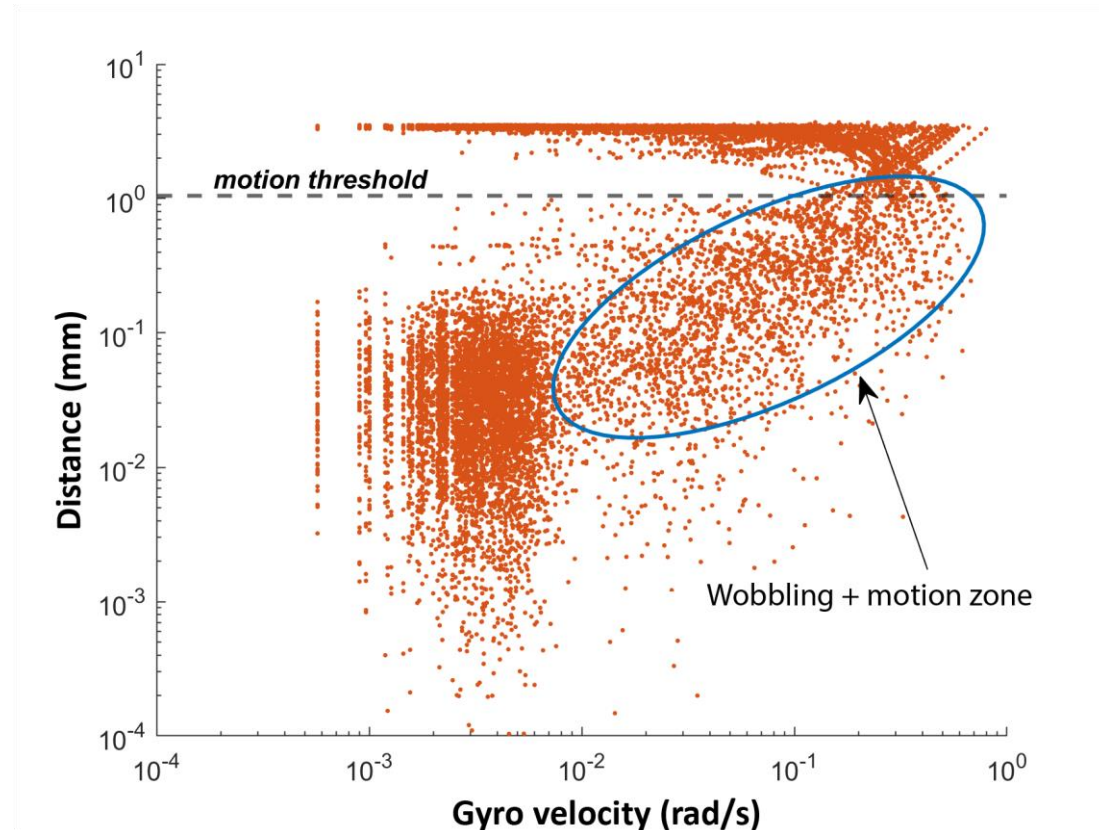


Figure S10. The variation of transport distance with angular velocity in the Al-Obaidi and Valyrakis (2021) flume experiment. In this setup, the smartrock was permitted to oscillate within a maximum range of 3.5 mm, constrained by a fixed pin that prevented further movement. The figure depicts states of rest (low gyro velocity), where the smartrock is either stationary or has reached the 3.5 mm limit. A highlighted section (blue ellipse) illustrates the transition zone, in which the the smartrock moves from a state of vibration to full displacement, with angular velocity values in this region ranging from 0.01 to 0.3 rad s^{-1} .

References

- AlObaidi, K., & Valyrakis, M. (2021). Linking the explicit probability of entrainment of instrumented particles to flow hydrodynamics. *Earth Surface Processes and Landforms*, 46(12), 2448–2465. <https://doi.org/10.1002/esp.5188>