Cascading Hazards: Triggering Relations Between Wet Tropical Cyclones, Landslides, and Earthquakes

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Earthquakes, landslides, and tropical cyclones are extreme hazards that pose significant threats to human life and property. Some of the couplings between these hazards are well known. For example, sudden, widespread landsliding can be triggered by large earthquakes and by extreme rainfall events like tropical cyclones. Recent studies have also shown that earthquakes can be triggered by erosional unloading over ~100-year timescales. We study triggering relations in Taiwan, which is subjected to very wet tropical storms, landslides, and earthquakes. One example for such triggering relations is the 2009 Morakot typhoon, which was the wettest recorded typhoon in Taiwan (2850 mm of rain in 100 hours). The typhoon caused widespread flooding and triggered more than 20,000 landslides, including the devastating Hsiaolin landslide. Six months later, the same area was hit by the 2010 M=6.4 Jiashian earthquake near Kaohsiung city, which added to the infrastructure damage induced by the typhoon and the landslides. Preliminary analysis of temporal relations between main-shock earthquakes and the six wettest typhoons in Taiwan's past 50 years reveals similar temporal relations between M≥5 events and wet typhoons. We suggest that the close proximity in time and space between wet tropical cyclones and earthquakes reflects a physical link between the two hazard types in which these earthquakes were triggered by rapid erosion induced by tropical cyclone's heavy rain. Based on remote sensing observations, meshfree finite element modeling, and Coulomb failure stress analysis, we show that the erosion induced by very wet cyclones increased the failure stresses at the hypocenters' depth by 300-1500 Pa, which ultimately triggered these earthquakes.