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Incorporating Hydrologic Monitoring into the Next Generation of Landslide Warning Systems

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Warning systems for rainfall-triggered shallow landsliding typically rely on empirical rainfall thresholds as a proxy for the subsurface conditions that actually lead to slope failure. This approach is supported by the wide availability of rainfall intensity and duration data, and further reinforced by the increasing accuracy of quantitative precipitation forecasts. Although elevated soil moisture and pore-water pressures are more reliable precursors to shallow landslide initiation, these hydrologic variables are difficult to measure and incorporate into early warning criteria. Considerable research has focused on increasingly complicated methods to estimate antecedent moisture conditions from rainfall data with mixed results and ambiguous explanations of failed and false alarms. We present both empirical and deterministic approaches to developing hydro-meteorological thresholds, which leverage rainfall forecasts and observations from near-real time networks of in-situ soil moisture sensors, to establish protocols for more accurate early warning of potential landsliding. Our empirical approach uses Receiver Operating Characteristics, landslide inventories, and hydrologic monitoring data to optimize different thresholds that can either be less risk tolerant or more averse to false alarms, depending on the user's requirements. The deterministic approach uses stochastic hourly rainfall and hydromechanical modeling to explore possible combinations of antecedent conditions and storms to extend the observed record, and to examine model sensitivity. Both approaches facilitate two-stage alerts for increased landslide potential. This new generation of hydro-meteorological thresholds could greatly improve landslide forecasting, which we demonstrate with hypothetical operational applications for several locations along the west coast of the United States.