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# Short-term sea cliff failure events accumulate into long-term cliff retreat signals

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Sea cliff retreat is an episodic process, where sudden landslide events punctuate longer periods of relative cliff stability. Understanding sea cliff behavior is key to defining coastal hazard zones or projecting future retreat due to sea level rise (SLR), when present. But, predicting when a particular landslide will occur, or how large it will be, is exceptionally difficult. As a result, rates of sea cliff retreat are often time-averaged over many individual landslides during a given time interval.

Time averaging of episodic processes like cliff retreat has several drawbacks, however. For one, the mean erosion or retreat rate can be heavily biased by the time interval over which it is measured, especially over short time scales (e.g. <10-20 years). Another inherent problem of time-averaged rates is the immediate loss of information about the short-term, seemingly random processes (i.e. landslides) that give rise to them. Is a mean long-term (multiple decades or longer) retreat rate caused by the accumulation of a few large landslides, or many smaller landslides? Or, consider the corollary: can observations of landslide size and frequency be used to infer long-term cliff retreat rates?

Fortunately the relationship between landslide area and frequency follows a predictable pattern in which landslide frequency (or probability) is a negative power law function of landslide area. Using on landslide frequency-area relationships determined using cliff edges extracted from 18 LiDAR surveys over a 12-year period in California (USA), we developed a simple cellular automata model of probabilistic cliff failure in order to link long-term and short-term cliff behavior. During a model time step, each alongshore cell on the cliff edge has a failure probability primarily determined by 1) a prescribed landslide frequency-area distribution and 2) beach width, so that the failure probability is lessened for wide beaches and vice versa. Beach width at each cell is determined by relative rates of cliff and beach erosion, driven by, for example, SLR or gradients in alongshore sediment transport. When a cliff failure occurs the cliff steps back and locally increases beach width – which temporarily decreases cliff failure probability until the beach width narrows enough to induce another failure. Over multiple decades to centuries, individual failure events coalesce into a characteristic, time-averaged, long-term cliff retreat signal. The magnitude of the emergent long-term rate depends on the migration rate of the beach fronting the cliff and the coefficients of the initial landslide frequency-area distribution.

Results allow direct inference between time-averaged cliff retreat rates and annual landslide probabilities. For example, in California, recent model projections have shown that a 1 m rise in sea level may cause currently observed long-term cliff retreat rates to almost double during the next century. Now, we can estimate with uncertainty 1) how such rate changes will potentially increase annual landslide probabilities and shorten recurrence intervals, 2) how long-term rates emerge from the accumulation of individual, instantaneous landslide events, and 3) the minimum time scale over which time-averaged retreat rates are representative of the long-term cliff retreat signal.