Establishing the timings of rainfall-triggered landslides using Sentinel-1 amplitude time series

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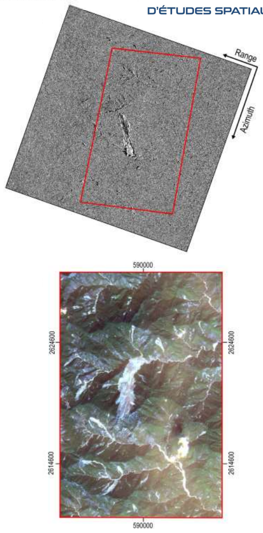
1. Landslide Mapping with optical satellite imagery

Why: For hazard assessment and to assess the impact of an event on the landscape
How: Comparison of optical satellite imagery acquired before and after the event
The problem: In tropical / sub-tropical countries, the wait for cloud-free optical satellite imagery can be several months long. Therefore the timings of landslides mapped at the end of long rainfall events is not known.

Sentinel-2 optical imagery acquired before and after landslides triggered in Hokkaido, Japan and an example of an unusable image

2. Synthetic Aperture Radar (SAR)

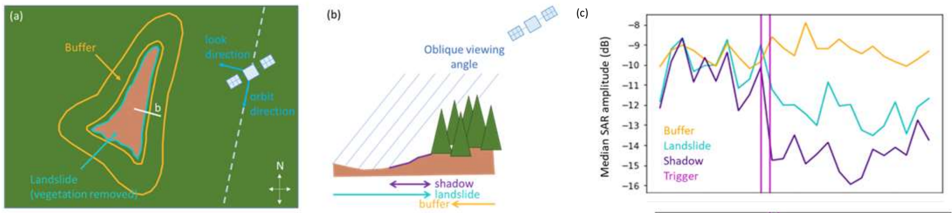
- SAR satellite actively illuminates the ground surface in microwave energy in order to acquire images. This can be done through cloud cover.
- The amplitude of the backscattered energy returned to the satellite is dependent on the conditions at the ground surface. In particular, SAR amplitude is sensitive to the dielectric properties, incidence angle and roughness of the ground.
- The removal of vegetation and movement of material caused by a landslide therefore changes the amplitude of the backscattered SAR. **SAR amplitude data are therefore sensitive to landslides.** However, the signal is complicated and landslides can result in both increases and decreases in amplitude.
- Sentinel-1 acquires images every 12 days on two tracks, allowing detailed time series to be constructed



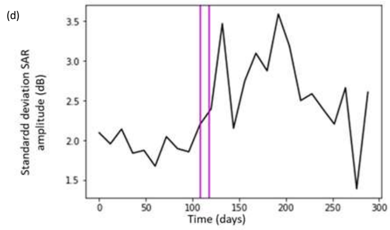
Difference between pre- and post- event Sentinel-1 SAR imagery (top) and GeoEye optical (bottom) imagery of the 2015 Tozang landslide (from Mondini et al. 2021)

3. Solution: Map landslides using optical imagery, then use Sentinel-1 time series to constrain their timing

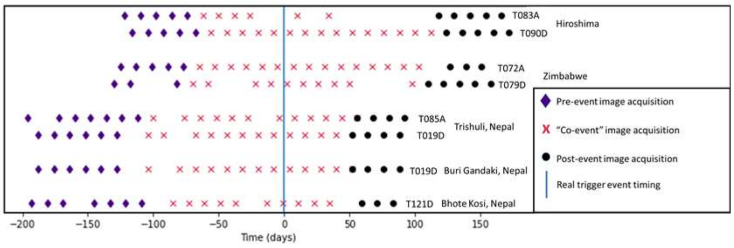
Technique 1: Increased variability in pixel amplitude within the landslide polygon
The removal of vegetation in a SAR image can result in increased pixel variability.
Technique 2: Difference between landslide and non-landslide time series
We compare the median amplitude of pixels within a landslide polygon (blue line) to the median amplitude of pixels within a buffer zone around the polygon that have a similar signal to the landslide in pre-event imagery (orange line).
Technique 3: Geometric Shadows
SAR imagery is acquired obliquely, which means that shadows can be cast at the edges of deforested areas (Bouvet et al. 2018). Landslide vegetation removal or steep landslide scars can therefore result in new shadows in a time series of SAR images. These are identified as pixels whose amplitude has decreased by >4.5 dB in post-event compared to pre-event imagery.



A landslide polygon, buffer and geometric shadow shown in (a) plan view (b) side view and (c) time series of the median pixel amplitude within the landslide (blue), its buffer (orange), geometric shadows (purple) using Sentinel-1 data for a landslide of known timing (pink vertical lines) (d) time series of standard deviation of pixels within the landslide polygon through time



All of these changes are expected to be permanent on the timescale we are looking at. Therefore, for each of these three techniques, we identify step changes by convolution with a step function



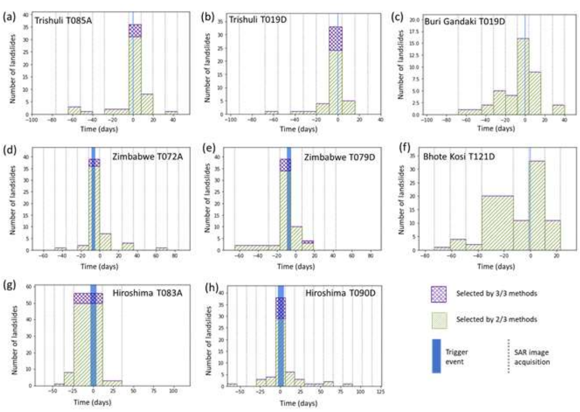
Timings of image acquisitions relative to trigger event timings

*"T083A" describes images acquired on **A**scending track number **83***

4. Test Cases

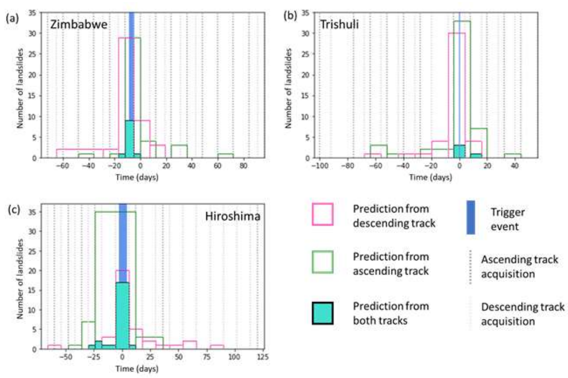
We tested the three techniques on landslides of known timing triggered by short rainfall events in Hiroshima and Zimbabwe (Emberson et al. 2021) and by the 2015 Gorkha, Nepal earthquake in the Trishuli, Buri Gandaki and Bhote Kosi valleys (from Roback et al. 2018). For each of these, we define a "co-event" period of around 6 months and try to predict the correct landslide timing within this window.

5.1 Results: Combined Methods



Distributions of predictions for each image time series. We require the same date to be predicted by a minimum of 2 of the 3 techniques described above, therefore not all landslides in an inventory are assigned a date.

5.2 Results: Combined Ascending and Descending tracks



Distributions of predictions made when the ascending and descending track data were combined (not possible in Buri Gandaki or Bhote Kosi, where only descending track data were available). Landslides dates can be estimated based on either the ascending or the descending track or by both tracks together. Since the two tracks are offset in time, landslides timed by both tracks are estimated within a smaller range.

6. Next Steps

We have demonstrated that Sentinel-1 time series can be used to time rainfall triggered landslides

The next stage of the research will be to apply these methods to optical inventories of monsoon-triggered landslides in Nepal for 2015, 2016 and 2017.

The timed landslide inventories will be used in physical and empirical models alongside satellite rainfall data to improve understanding of the physical processes behind rainfall-triggered landsliding in the Nepal Himalaya

References

Bouvet, A., et al. 2018. Use of the SAR shadowing effect for deforestation detection with Sentinel-1 time series. *Remote Sensing*, *10*(8), p.1250.
Emberson, R., et al. 2021. Insights from the topographic characteristics of a large global catalog of rainfall-induced landslide event inventories. *Natural Hazards and Earth System Sciences Discussions*, pp.1-33.
Mondini, A.C., et al. 2021. Landslide failures detection and mapping using Synthetic Aperture Radar: Past, present and future. *Earth-Science Reviews*, p.103574.
Roback, K.,et al. , 2018. The size, distribution, and mobility of landslides caused by the 2015 Mw7. 8 Gorkha earthquake, Nepal. *Geomorphology*, *301*, pp.121-138.