Establishing the timings of rainfall-triggered landslides using Sentinel-1 satellite radar data

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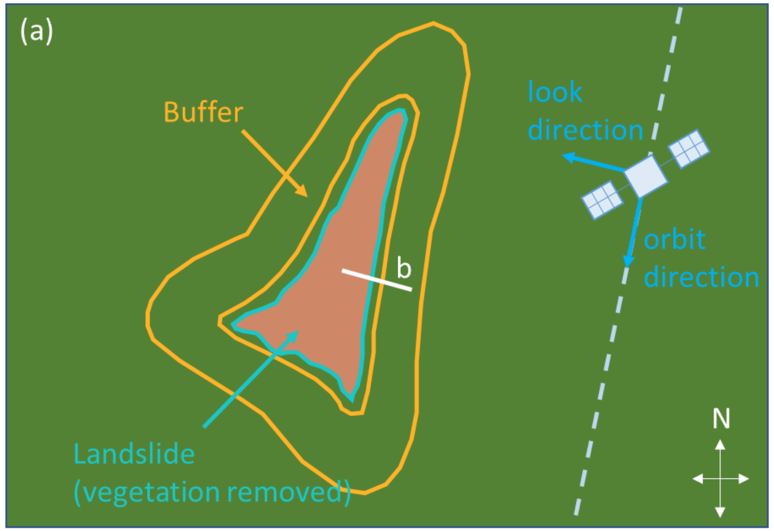
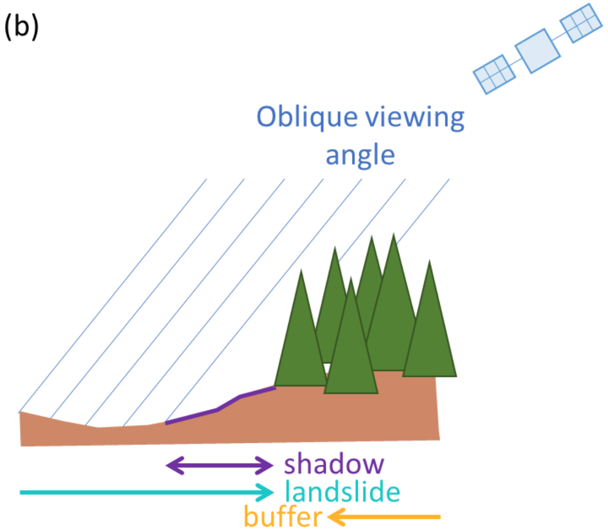
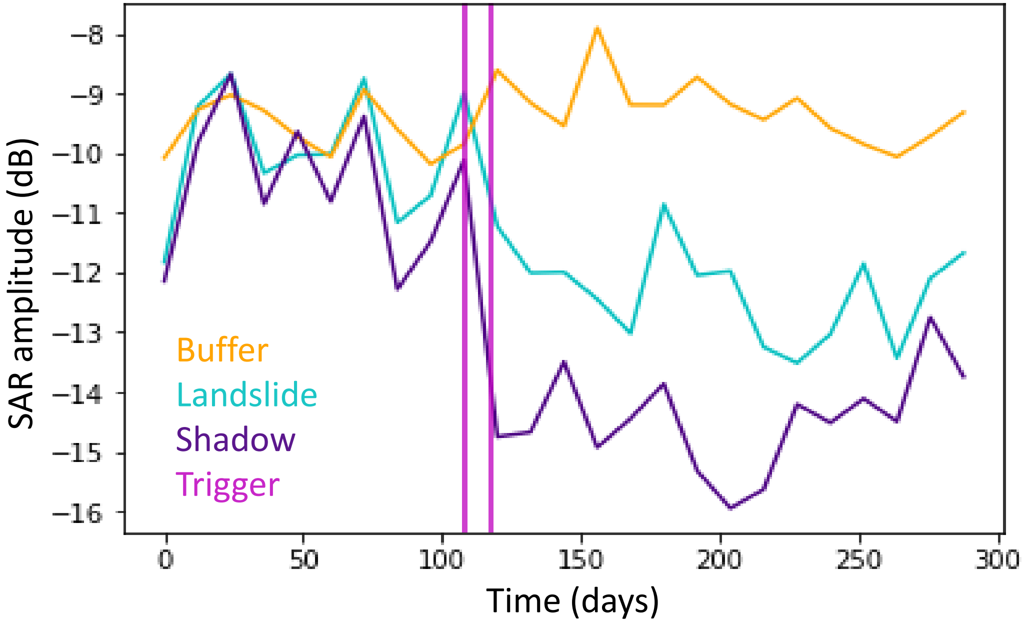
- Cloud cover often means that the timings of rainfall-triggered landslides are poorly constrained when they are mapped using optical satellite imagery.
- Sentinel-1 radar satellite imagery is acquired every 12 days globally. The removal of vegetation and movement of material gives landslides a signal in these data
- We present a method in which Sentinel-1 satellite radar data is used to identify landslide timing through comparison of the signal amplitude within the landslide, within a buffer region, and in geometric shadows.
- Using this method, Sentinel-1 data can be used to improve the temporal resolution of landslide inventories mapped using optical satellite imagery at the end of long rainfall events such as the Nepal monsoon.







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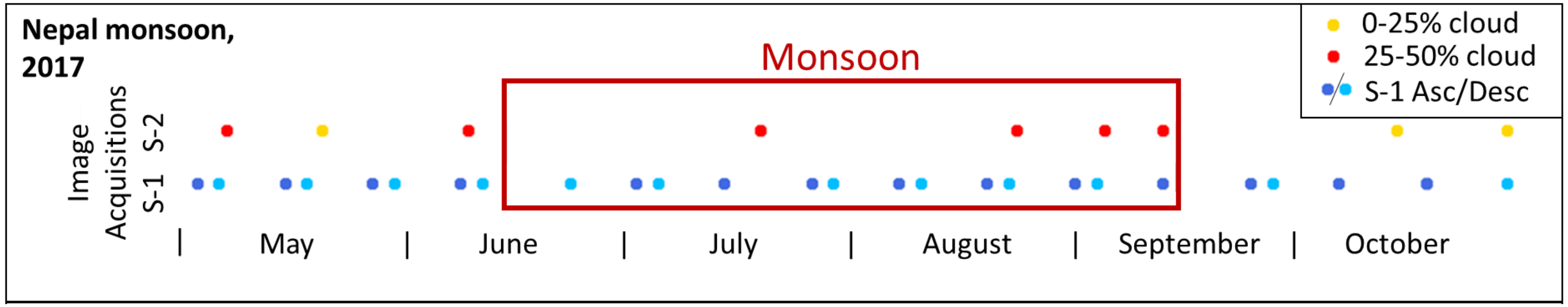
Motivation

Physical and empirical models of rainfall-triggered landslides are used for hazard assessment and to further our understanding of the physical processes. This requires information both on the spatial extent and timing of landslides.



Comparison between usable imagery acquired by the European Space Agency's Sentinel-1 (radar) and Sentinel-2 (optical) satellites during the 2017 Nepal monsoon season . Sentinel-1 imagery is acquired every 12 days on two tracks. Sentinel-2 imagery is acquired every 10 days but is frequently obscured by cloud cover.

Optical/multispectral satellite images are commonly used to map landslides. These data have fine spatial resolution and high accuracy. However, when cloud cover obscures the imagery for long periods of time, for example the Nepal monsoon, landslide information obtained from optical satellite imagery is poorly constrained in time (e.g. yearly in Marc et al. 2019).

Sentinel-1 Synthetic Aperture Radar (SAR) images are acquired every 12 days on two tracks in all weather conditions and so have a better temporal resolution. However, these data are usually only applied at coarse spatial resolutions (e.g. Burrows et al. 2020) or to individual large landslides (e.g. Mondini et al. 2019).

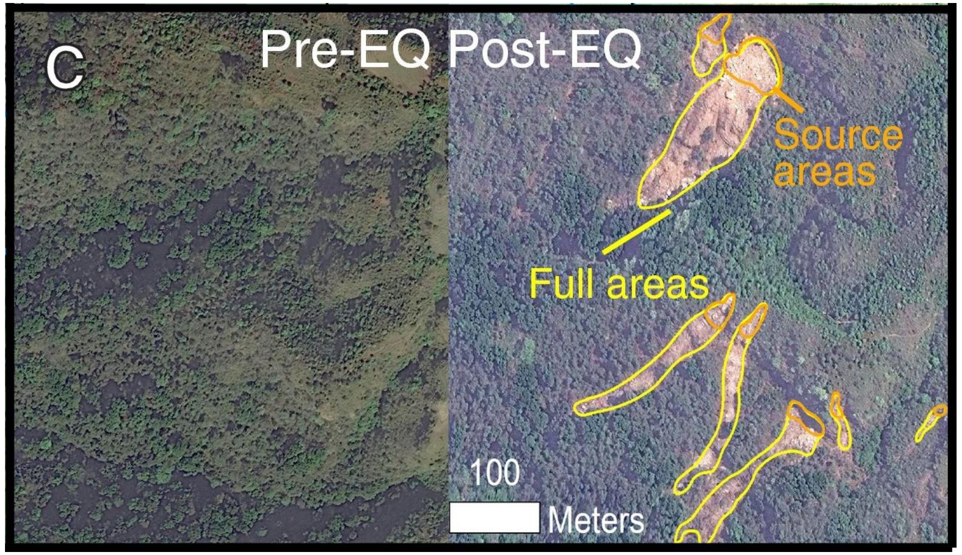
Solution: Map the landslides after the rainfall event using optical imagery. Then use Sentinel-1 time series data to assign dates to the landslides.

Landslide data from optical satellite imagery

In order to develop and test methods using Sentinel-1 data to identify landslide timings, we need inventories of landslides whose timings are already known. In all cases, we use only landslides with an area > 2000 m^2. We use polygon landslide inventories compiled from high resolution optical imagery following two events:

1. **Earthquake triggered landslides in Nepal**. 650 landslides in Trishuli and 386 in the Bhote Kosi Valley from the inventory of Roback et al. (2018). We assume these landslides are concurrent with the earthquake on 25th April, 2015.
2. **Rainfall-triggered landslides in Hiroshima, Japan.** 542 landslides associated with heavy rainfall between 28th June and 8th July 2018 (Unpublished inventory)

Both of these case studies occurred in vegetated areas and in parts of the world which frequently experience rainfall-triggered landsliding.



Landslides mapped by Roback et al. (2018) through comparison of optical satellite imagery acquired before and after the 2015 Gorkha, Nepal earthquake

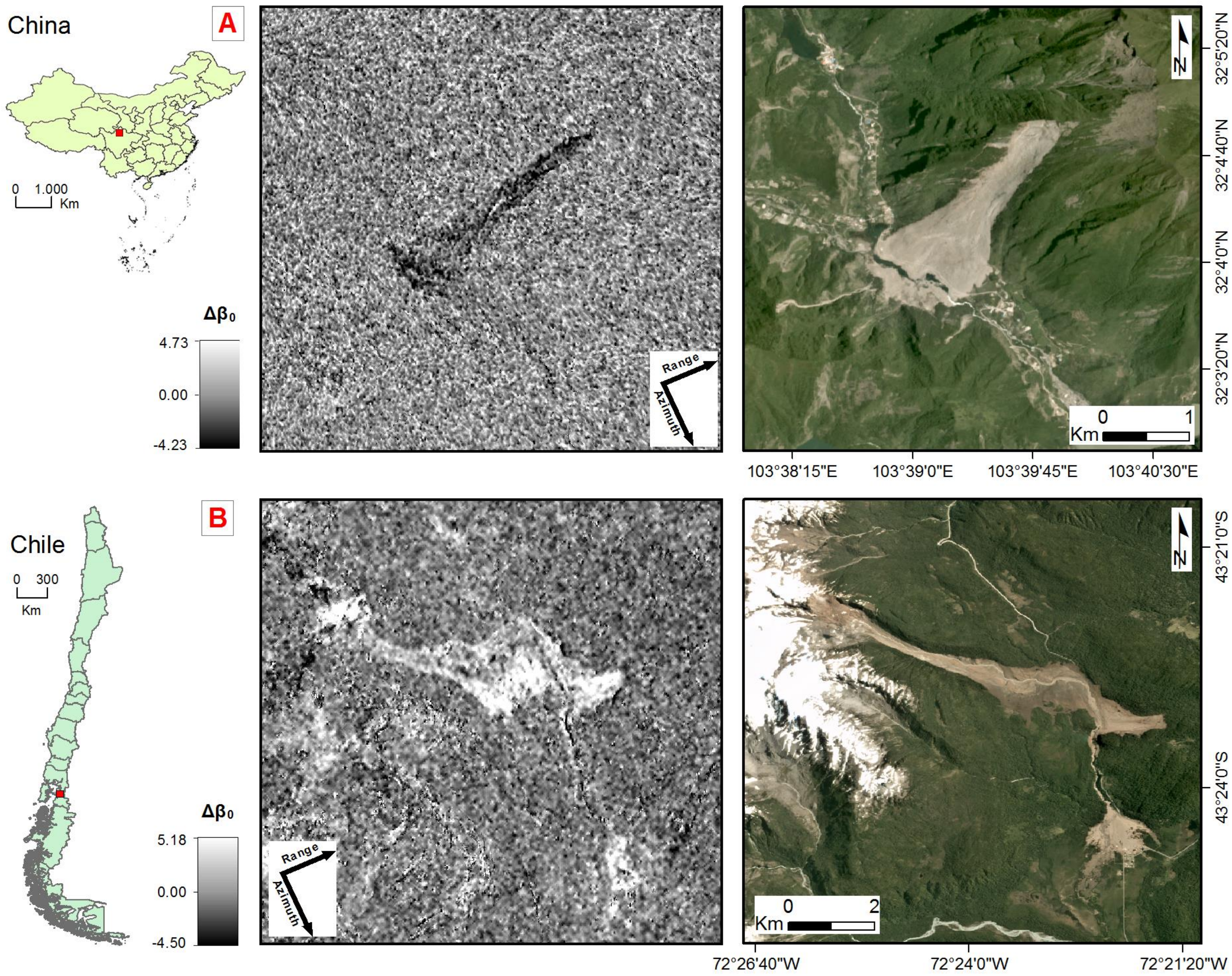
Theory: landslide detection with SAR amplitude

A SAR system actively illuminates the Earth's system in microwave radiation and records the returned signal

The amplitude of this signal is dependent on the material interacted with at the Earth's surface (land cover type) and on its dielectric properties (e.g. soil moisture content) as well as on slope orientation relative to the sensor

The movement of material and removal of vegetation caused by a landslide results in a change in amplitude in SAR imagery.

Change in SAR amplitude *Optical image of landslide*



Landslides result in SAR amplitude change (Mondini et al. 2019)

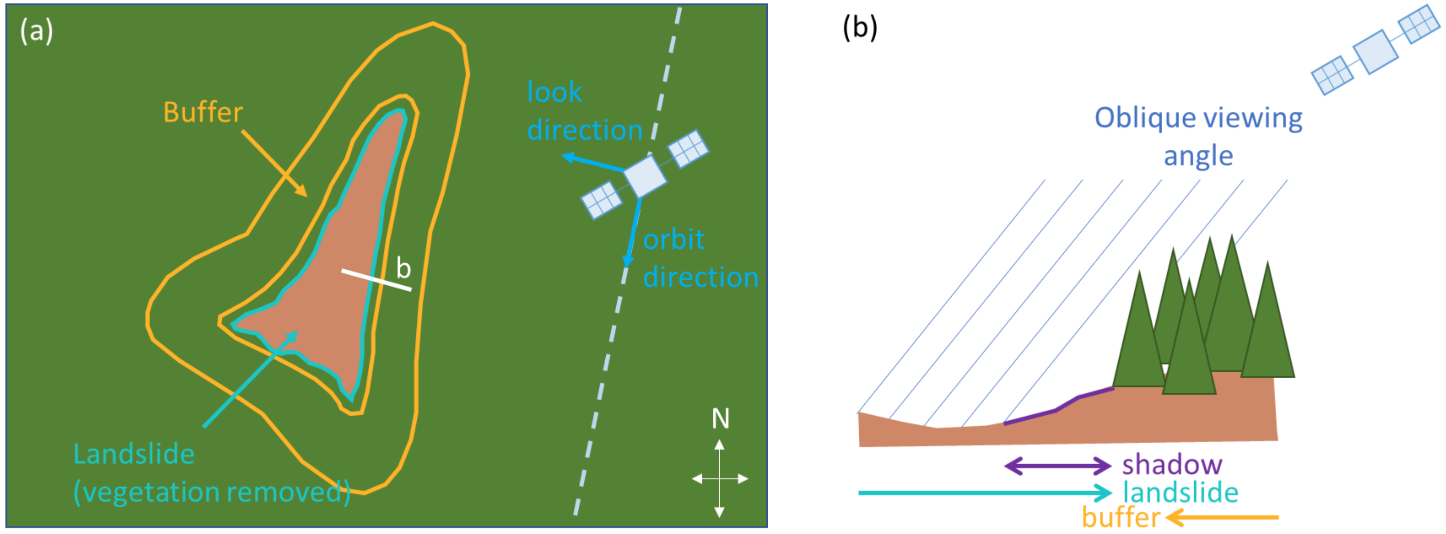
Methods: amplitude behaviour through time

We compare the time series of Sentinel-1 amplitude for three areas:

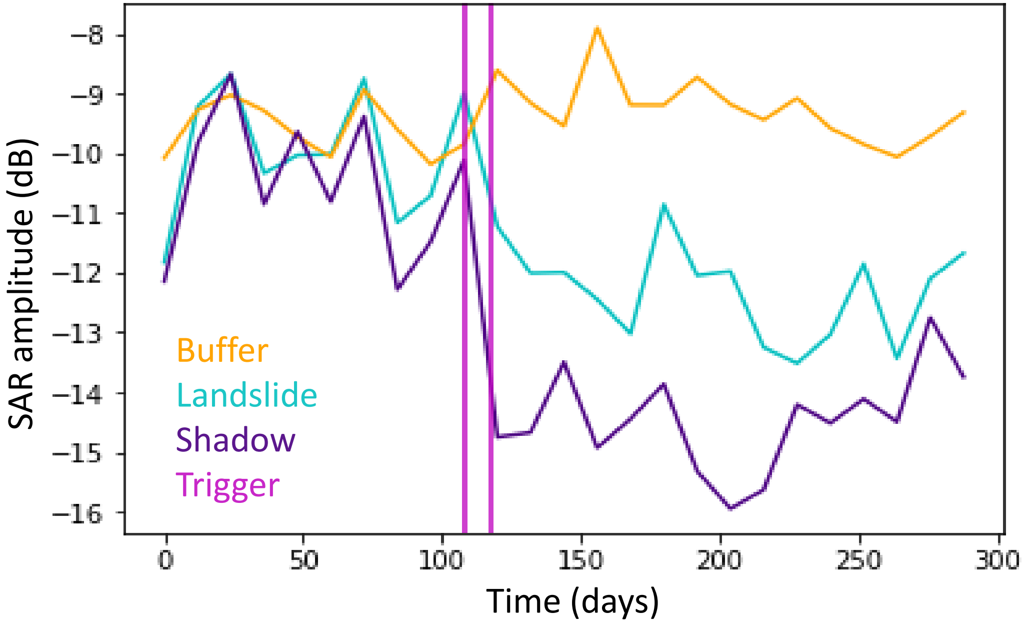
1. Within the landslide polygon
2. Within a buffer zone >10m and <50m from the landslide (to represent background amplitude)
3. Within geometric shadows identified in post-event but not pre-event SAR imagery. Bouvet et al. (2018) demonstrated that when an area is deforested, new geometric shadows can appear in Sentinel-1 SAR images cast by the trees at the edges of the deforested areas.

We use Sentinel-1 GRD data, which has a 10 m spacing. The minimum landslide size is 2000 m^2. Therefore each landslide should contain a minimum of ~ 20 SAR pixels.

The analysis was carried out using Google Earth Engine



Definitions of the landslide polygon, the buffer region and the geometric shadow. Imagery is acquired obliquely in a direction perpendicular to the movement of the satellite.



An example of mean amplitude through time for one landslide triggered by rainfall in Hiroshima, its buffer and its shadows. A step change in the landslide and shadow pixels is seen following the rainfall event indicating the landslide timing.

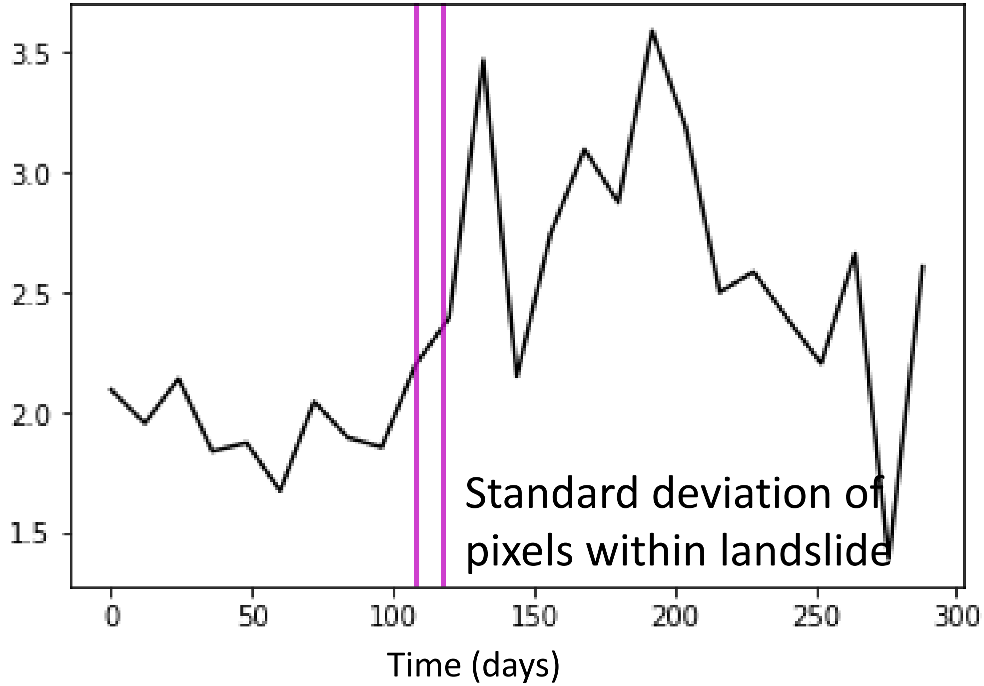
Methods: amplitude behaviour through time

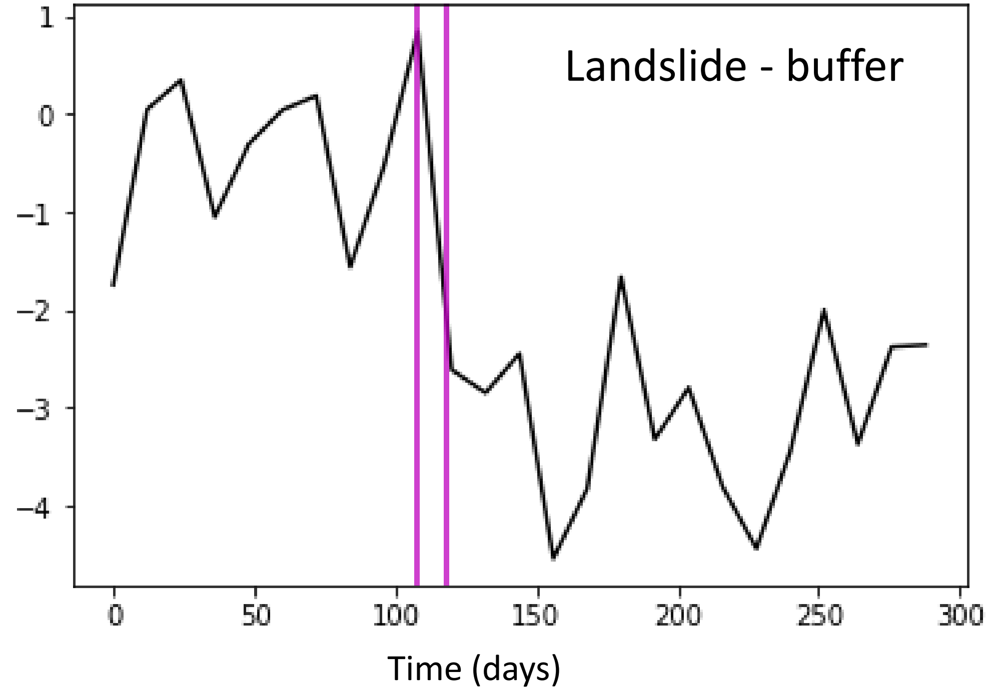
We find the following methods can be used to indicate landslide timing:

1. A step change in mean landslide amplitude
2. A step change in the difference between the mean amplitude of the landslide and its buffer
3. A step increase in the standard deviation of pixel amplitudes within the landslide
4. A step decrease in the mean amplitude of any new geometric shadows (Bouvet et al. 2018)
5. A step decrease in the mean amplitude of any new geometric shadows compared to the mean amplitude of the landslide polygon

We identify the timing of the step change through convolution with a step function.

All of these methods perform better than random at selecting the correct landslide timing, but we can combine them to improve accuracy.





Combination of Ascending and Descending tracks

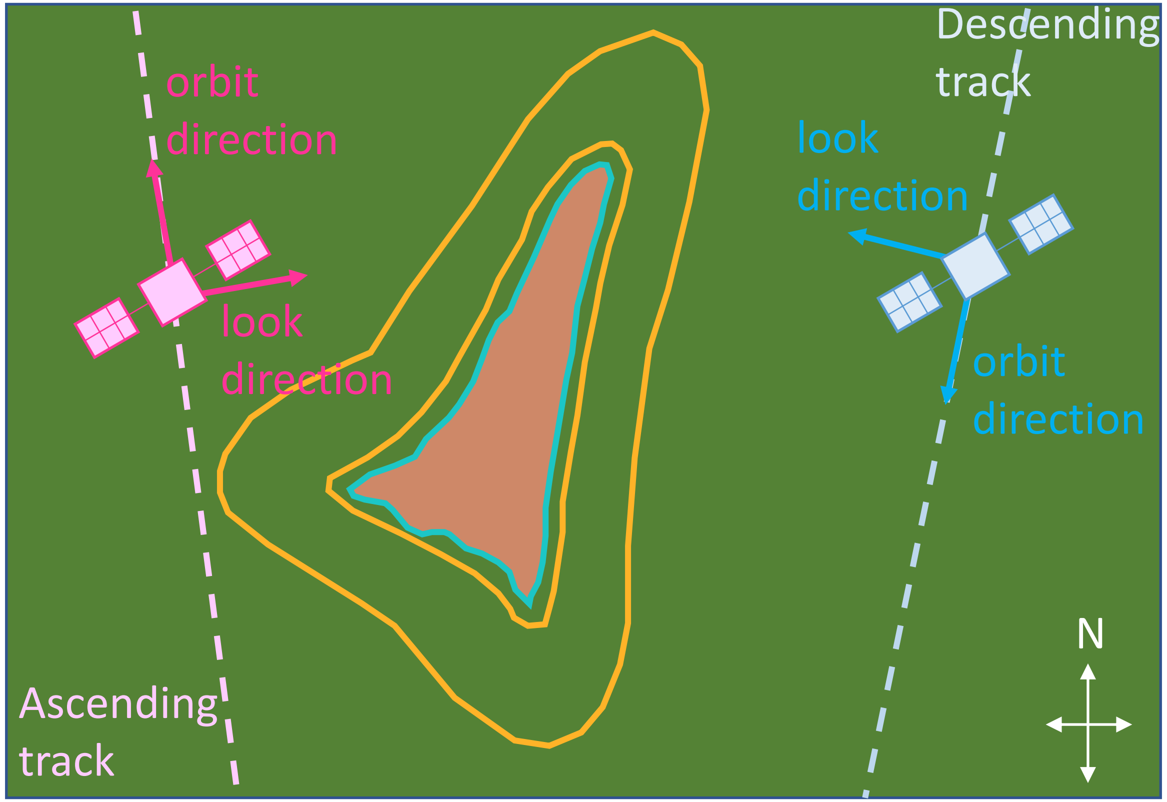
SAR data is acquired obliquely on two tracks: one ascending and one descending

- Ascending track: satellite moves in a South - North direction looking East
- Descending track: satellite moves in a North – South direction looking West.

We can combine predictions from both tracks, which has two advantages:

1. Landslides poorly oriented to one track should be better imaged by the other

2. Landslides well imaged by both tracks have improved resolution in time since the ascending and descending track acquisitions are offset in time.



Testing the methods

- By testing these methods on landslide inventories whose timings are already known (slide 3), we can assess how accurately we can use Sentinel-1 amplitude to identify landslide timing
- We used each method to predict the 12-day Sentinel-1 window of each landslide from within a 3 month window.
- Not all methods produce a prediction, for example if there are no geometric shadow pixels
- This is repeated on both the ascending and descending track.
- For every landslide we have a collection of predictions for each track. We define the minimum number of times a date has to be predicted for it to be considered. The most common prediction is assigned to the landslide. If the ascending and descending predictions overlap, the temporal resolution can be improved.

Results

Results when we require the same date to be selected by three methods to assign it to a landslide

Inventory	No. landslides in inventory	No. landslides assigned a date	No. landslides assigned correct date	No. landslides assigned by both tracks
Bhote-Kosi, Nepal	388	60	56 (80%)	2
Trishuli, Nepal	650	219	140 (64%)	17
Hiroshima, Japan*	542	93	43 (46%)	N/A

Results when we require the same date to be selected by four methods to assign it to a landslide

Inventory	No. landslides in inventory	No. landslides assigned a date	No. landslides assigned correct date	No. landslides assigned by both tracks
Bhote-Kosi, Nepal	388	28	23 (80%)	1
Trishuli, Nepal	650	161	118 (73%)	9
Hiroshima, Japan*	542	31	18 (58%)	N/A

*Hiroshima only contains dates predicted using the descending track

Conclusions

- Landslides are often poorly constrained in time due to cloud cover in optical satellite imagery.
- We propose a two step process in which landslides are mapped using optical satellite imagery and then assigned a timing using Sentinel-1 SAR imagery
- To assign this timing, we compare the amplitude of pixels within the landslide polygon, within a buffer region outside the landside and within geometric shadows
- We can use a combination of methods to identify landslide timing using Sentinel-1 GRD data. If more methods are required to predict the same dates before they are assigned, fewer landslides are assigned a date, but a higher proportion will be correct

References

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