Rainfall-triggered landslide timings from Sentinel-1 SAR time series: Application to the Nepal monsoon

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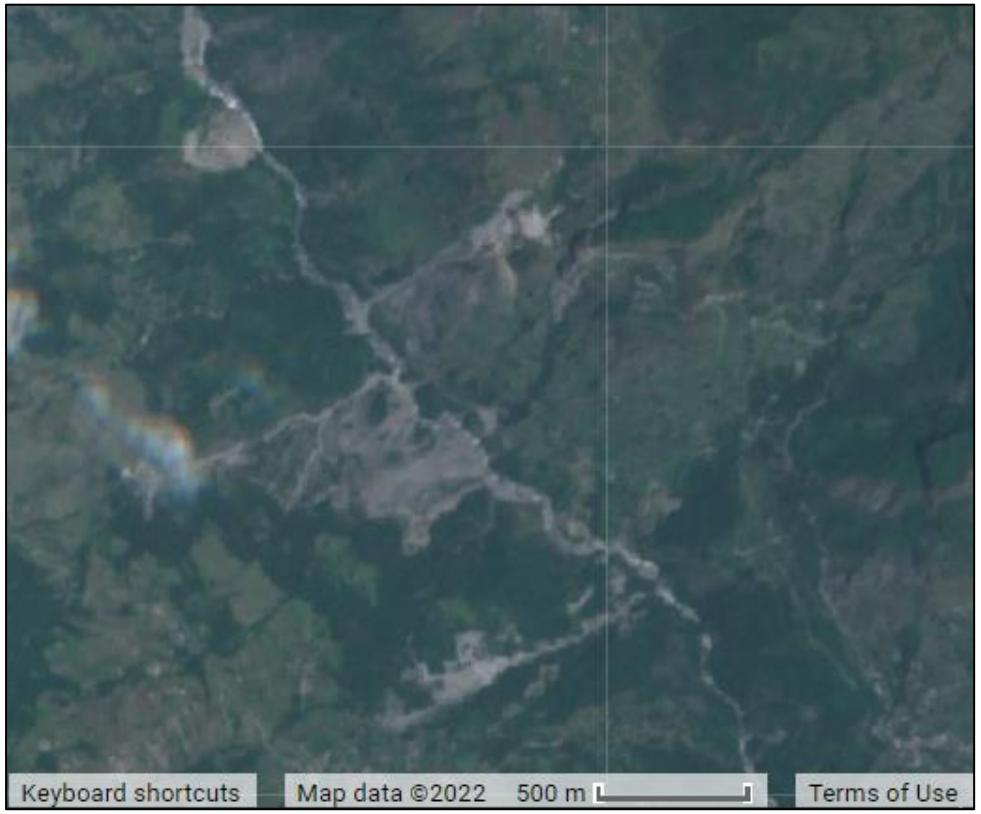
Motivation

- Rainfall-triggered landslides cause widespread damage and disruption every year
- Significant mass wasting effect
- Models used to predict future hazard and to assess the impact an event has had on the landscape
- We need to know **when and where** landslides have occurred to calibrate these models

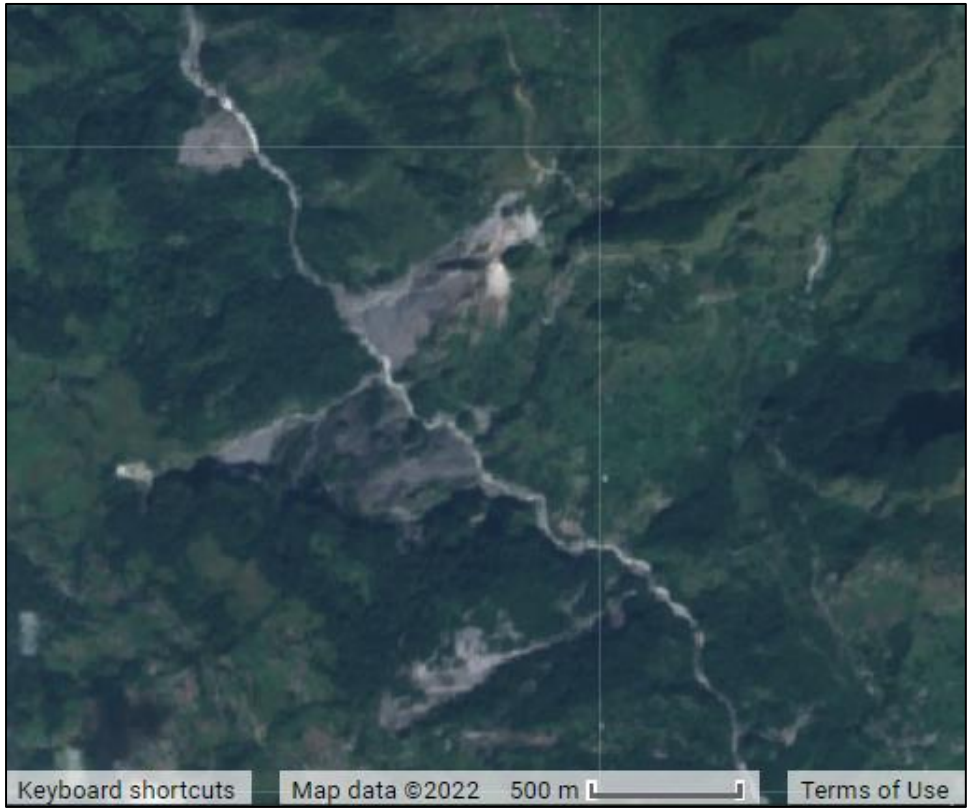
Infrastructure at risk from landsliding along the Arniko Highway, Sinhupalchok, Nepal

Mapping monsoon-triggered landslides with optical satellite images

Comparison between images acquired before and after the monsoon – identify new failures



Pre-monsoon, Nepal, 2017
Sentinel-2



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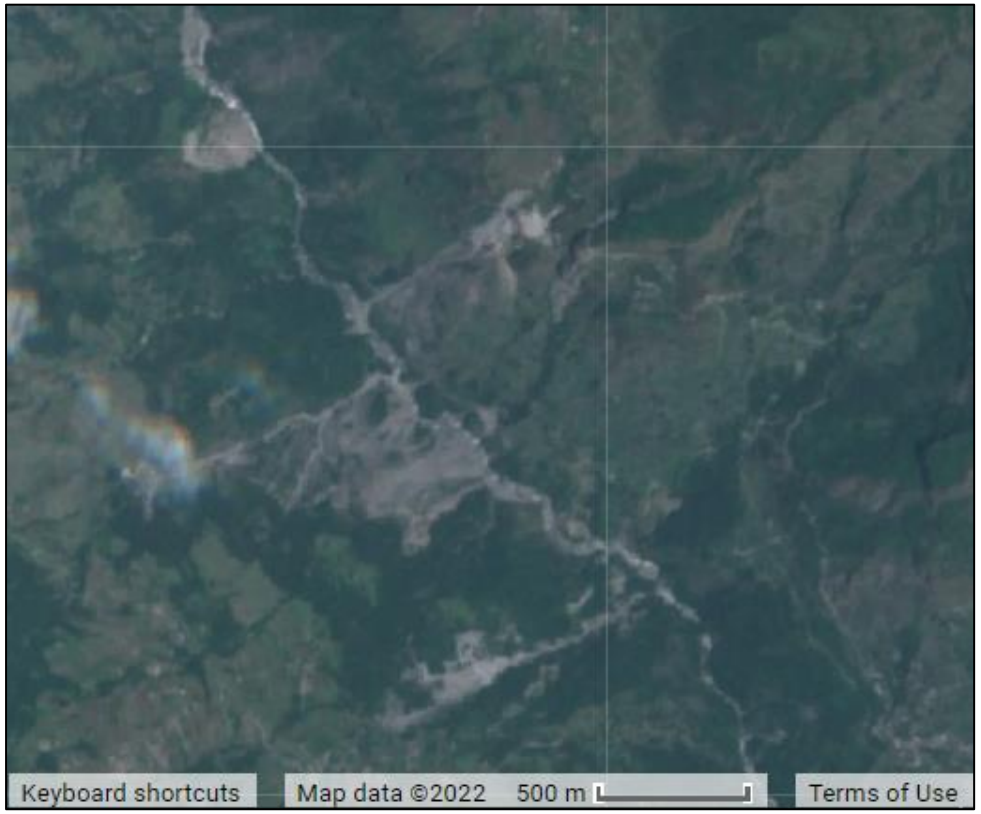

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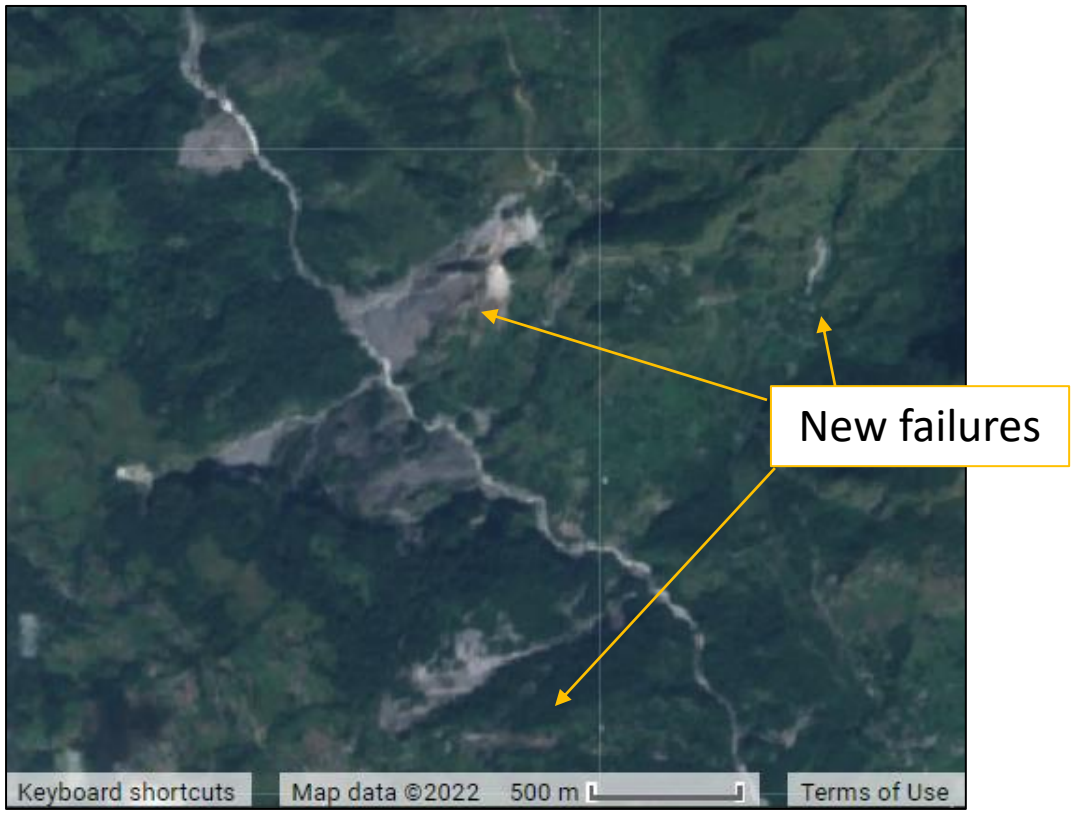

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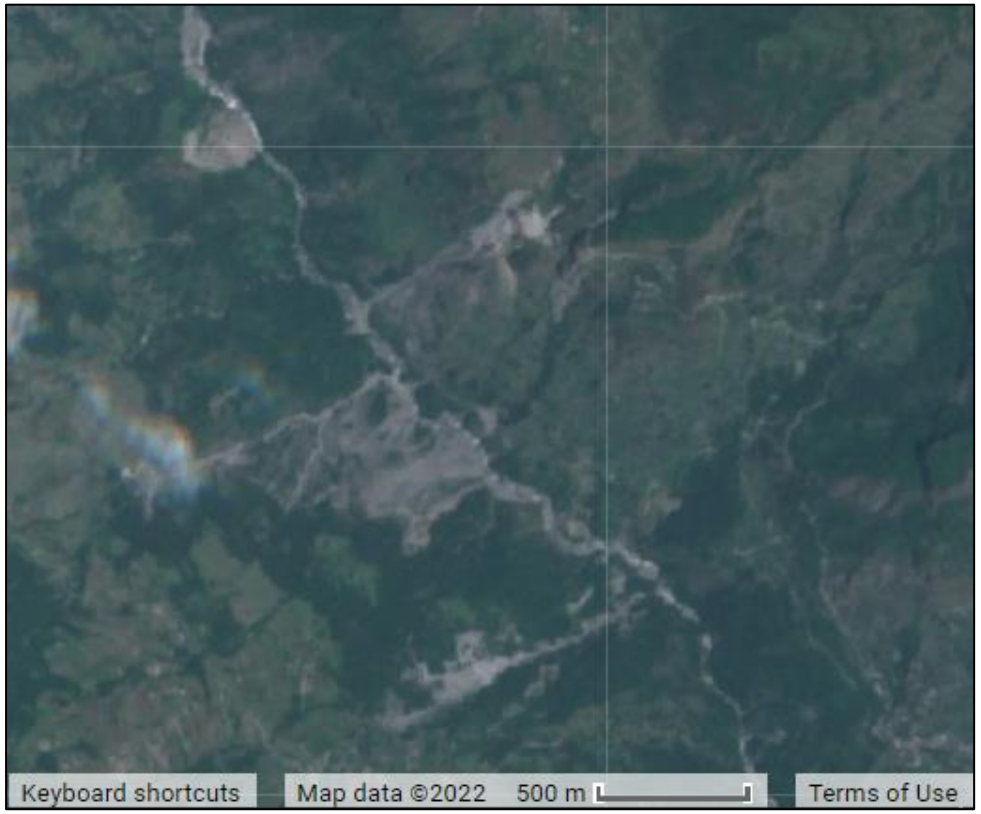

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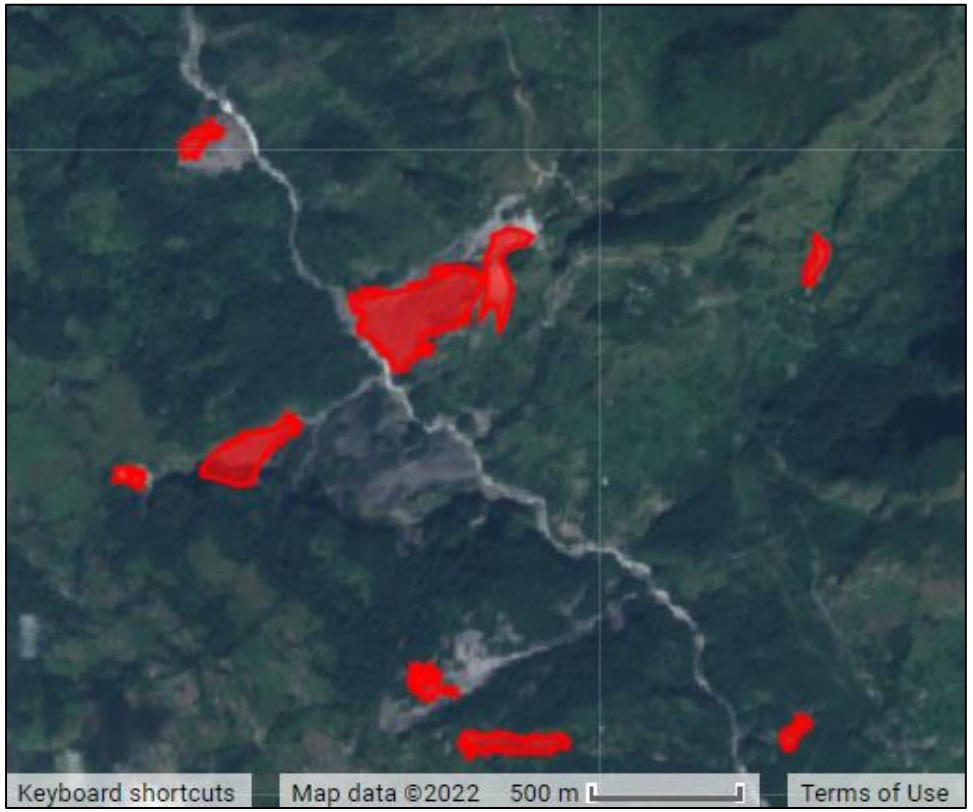

Post-monsoon, Nepal, 2017
Sentinel-2, Polygons from Marc et al. (2019)

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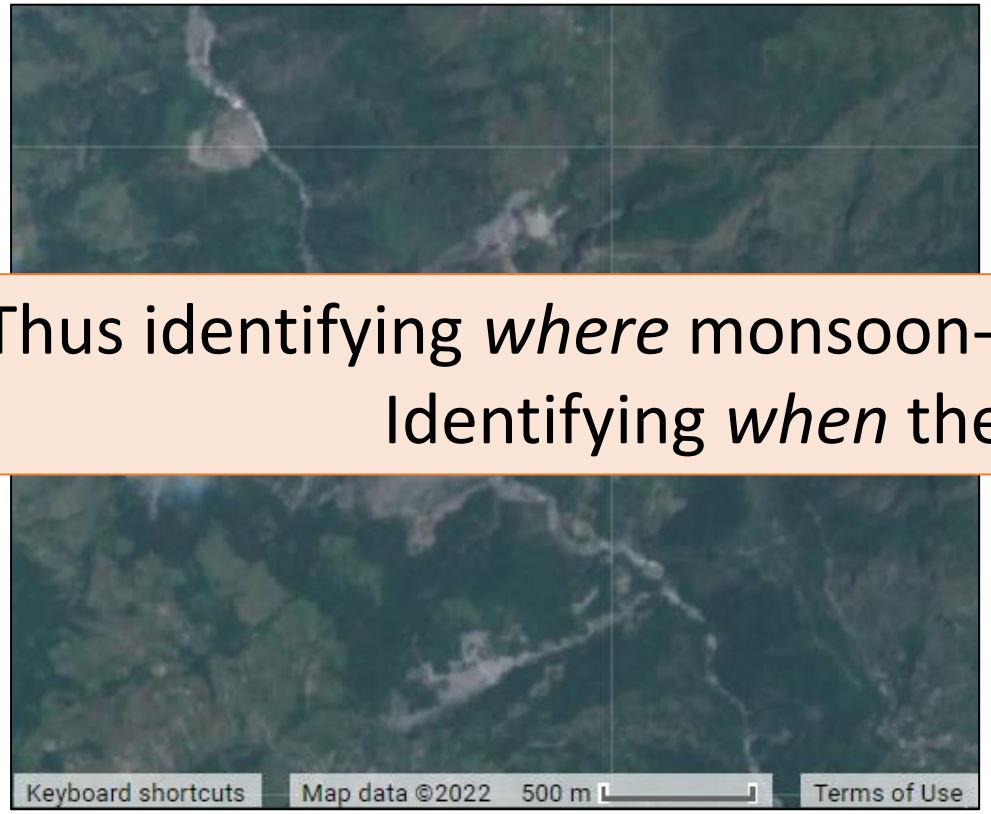
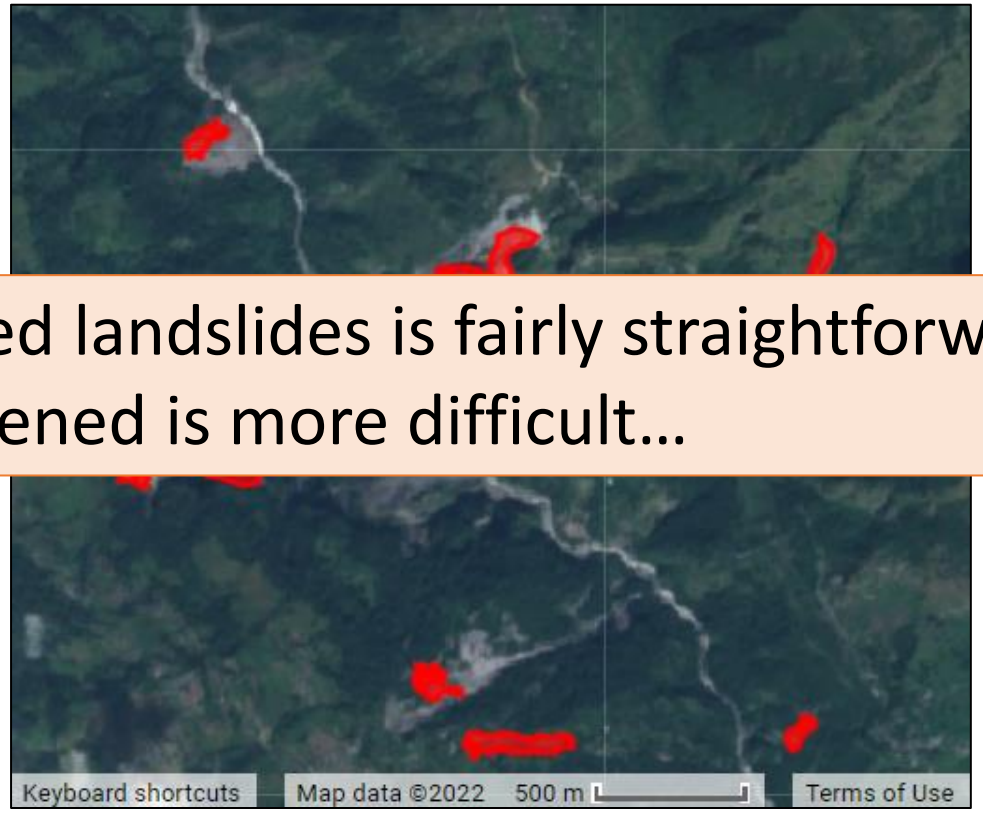


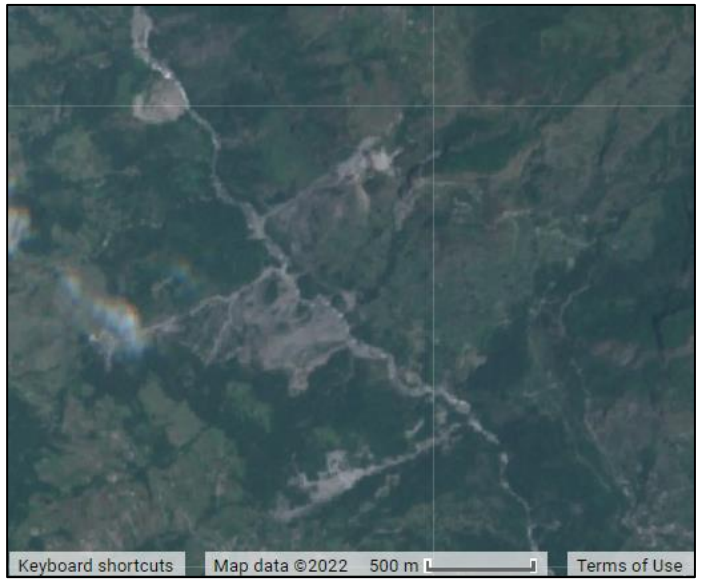
Pre-monsoon, Nepal, 2017
Sentinel-2



Post-monsoon, Nepal, 2017
Sentinel-2, Polygons from Marc et al. (2019)

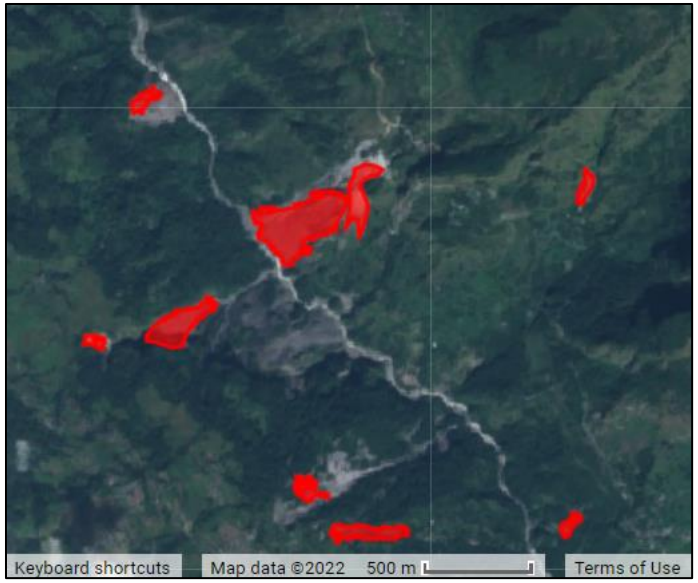
Thus identifying *where* monsoon-triggered landslides is fairly straightforward.
Identifying *when* they happened is more difficult…

Mapping monsoon-triggered landslides with optical satellite images



Pre-monsoon, Kali Gandaki, 2017
Sentinel-2

During the monsoon (May – Sept) Sentinel-2



Post-monsoon, Nepal, 2017
Sentinel-2

Usable images are not available during the monsoon season due to cloud cover

We cannot tell when the landslides happened

Importance of landslide timing

Annual landslide volume affected by:

1. Average monsoon strength
2. Short intense periods of rainfall

To associate landslides with short periods of intense rainfall, we need information on their timing

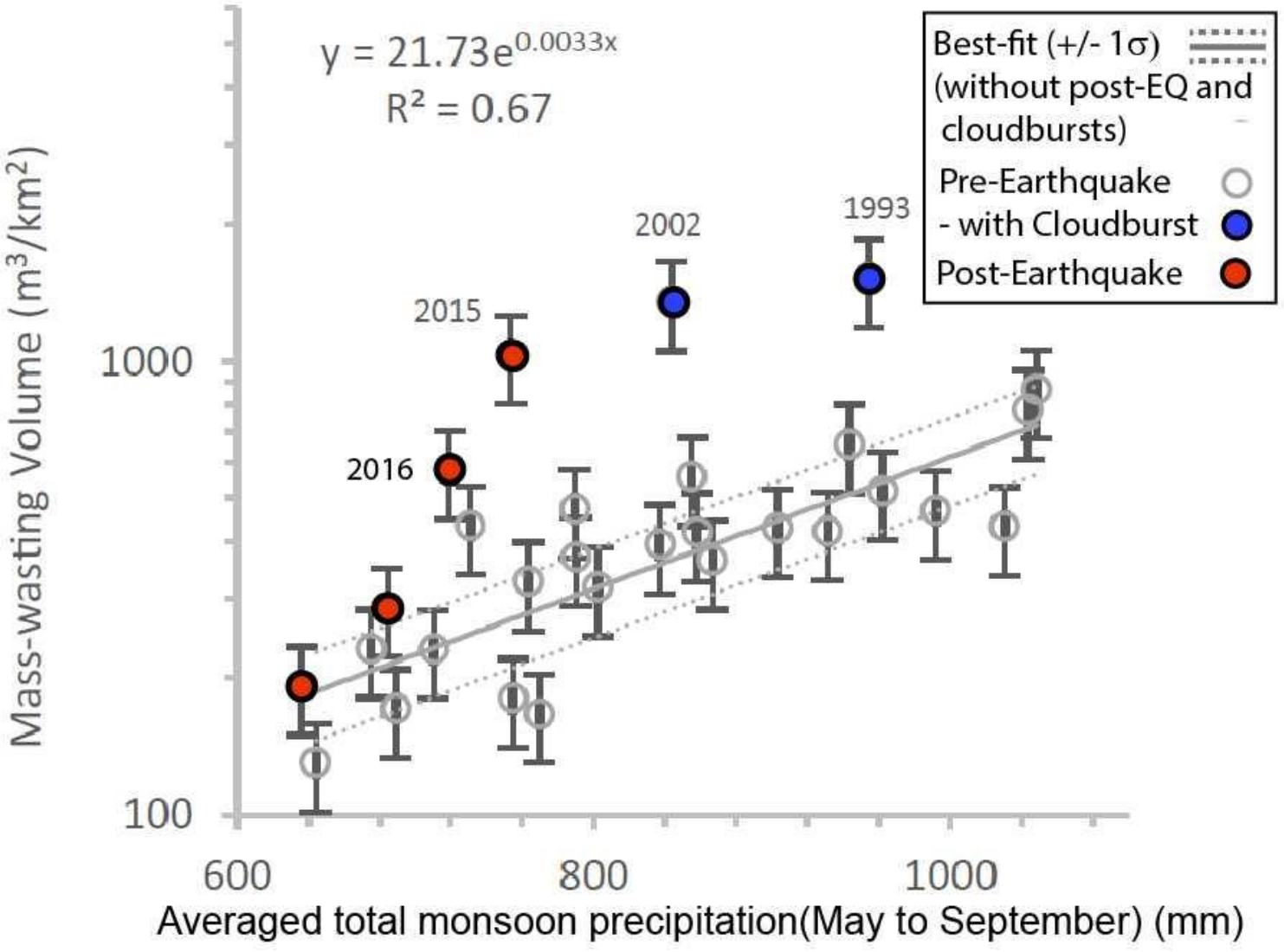


Figure showing estimated mass-wasting volumes for landslides triggered during different monsoon years. Modified from Jones et al. (2021)

Sentinel-1 SAR for landslide detection

- Signal amplitude depends on the scattering properties of the Earth's surface
- **Sensitive to landslides**
- **Images can be acquired through cloud cover**

Sentinel-1:

- Launched in 2014
- Images acquired **every 12 days** on 2 tracks globally
- Google earth engine dataset with 10 x 10 m pixels

Sentinel-1 SAR for landslide detection

- Signal amplitude depends on the scattering properties of the Earth's surface
- **Sensitive to landslides**
- **Images can be acquired through cloud cover**

Sentinel-1:

- Launched in 2014

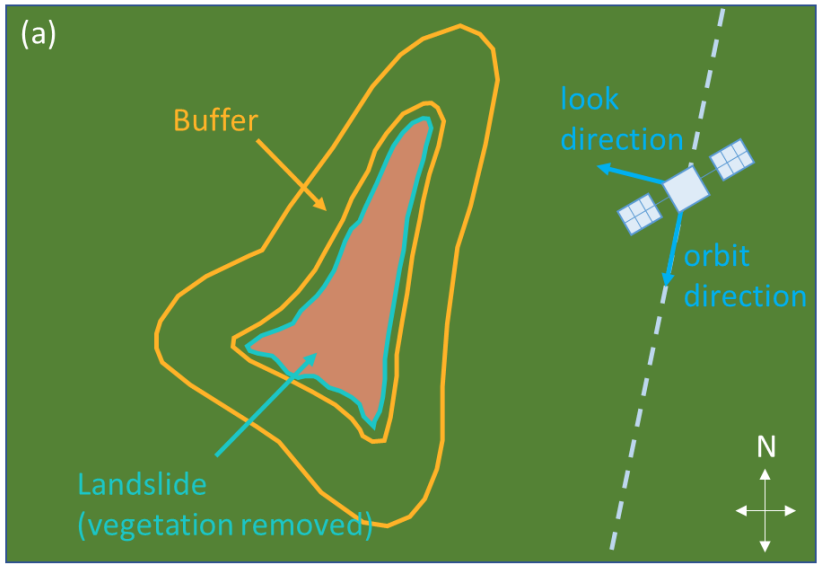
Proposed 2 step process:

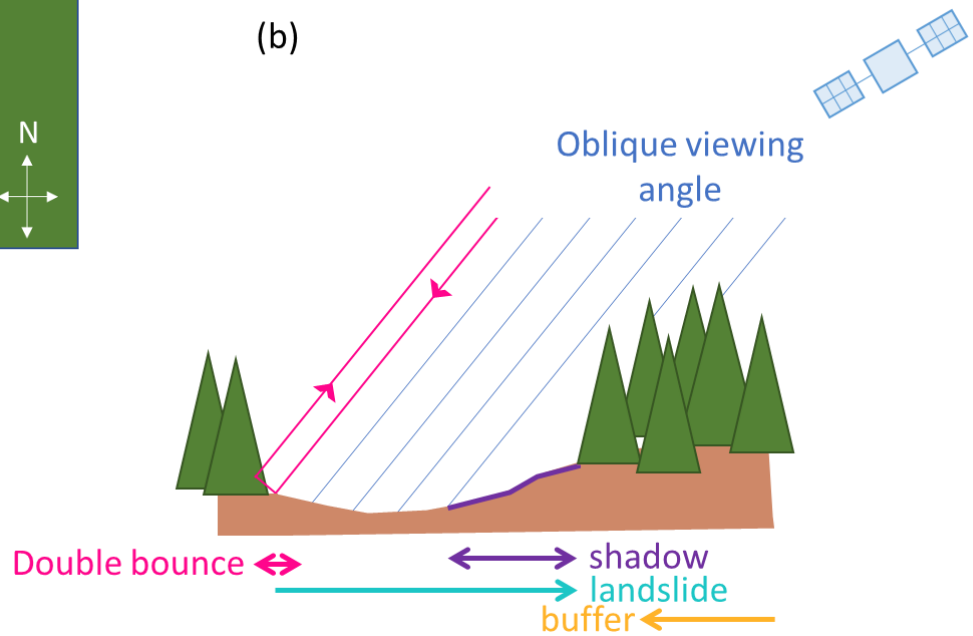
1. Map landslide polygons in optical satellite imagery
2. Using Sentinel-1 time series to establish the timings of individual polygons

Sentinel-1 SAR for landslide detection

4 Methods for landslide timing:

1. Difference in median amplitude between landslide and background pixels
2. Increased amplitude variability
3. Geometric shadows (dark)
4. Double bounce (bright)

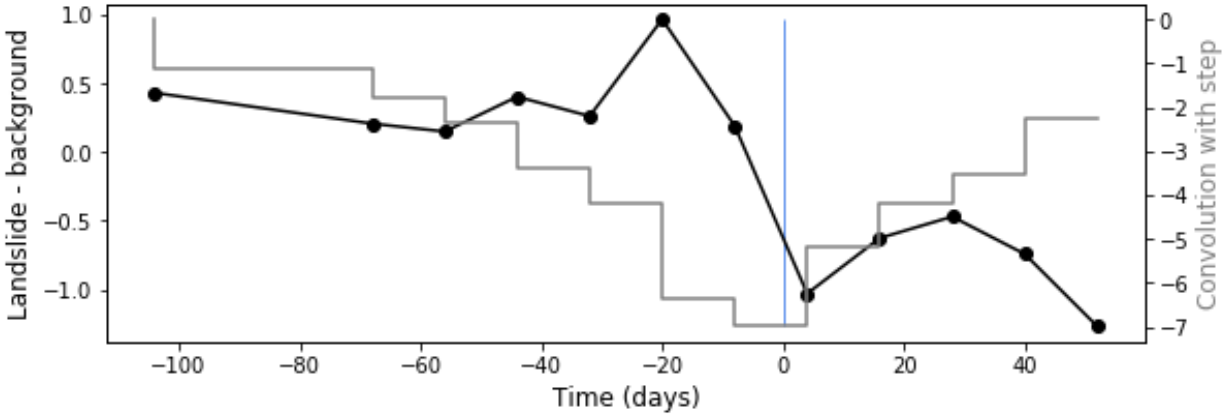




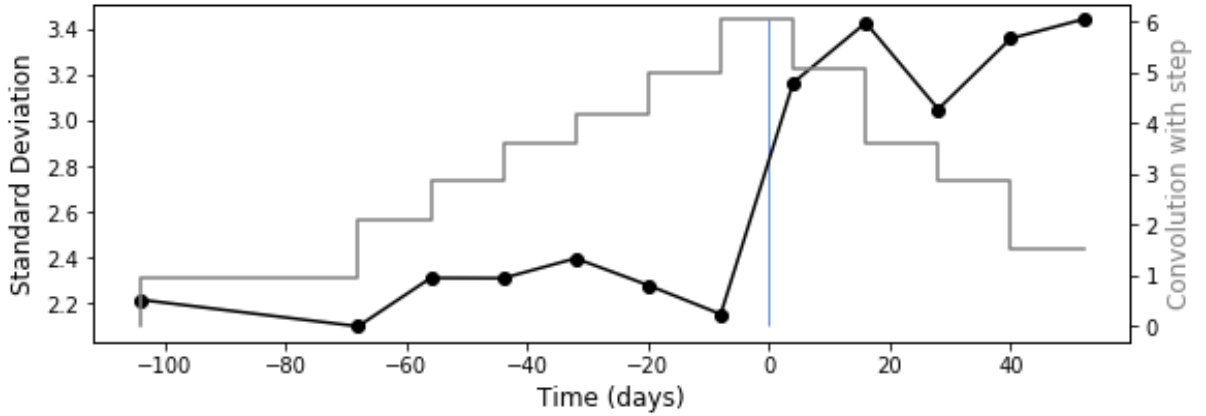
Burrows et al. (in review, NHESS)

Sentinel-1 SAR for landslide detection

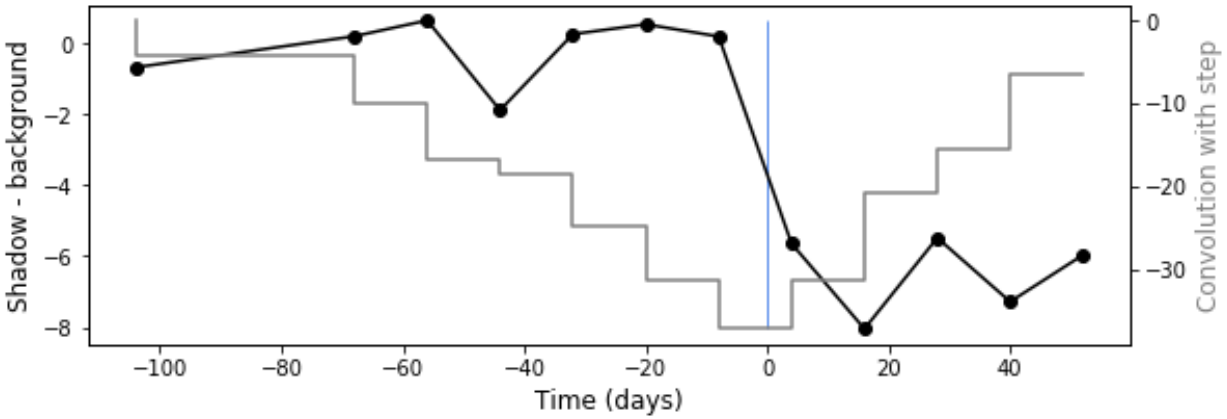
Landslide - background



Amplitude variability



Shadow - background

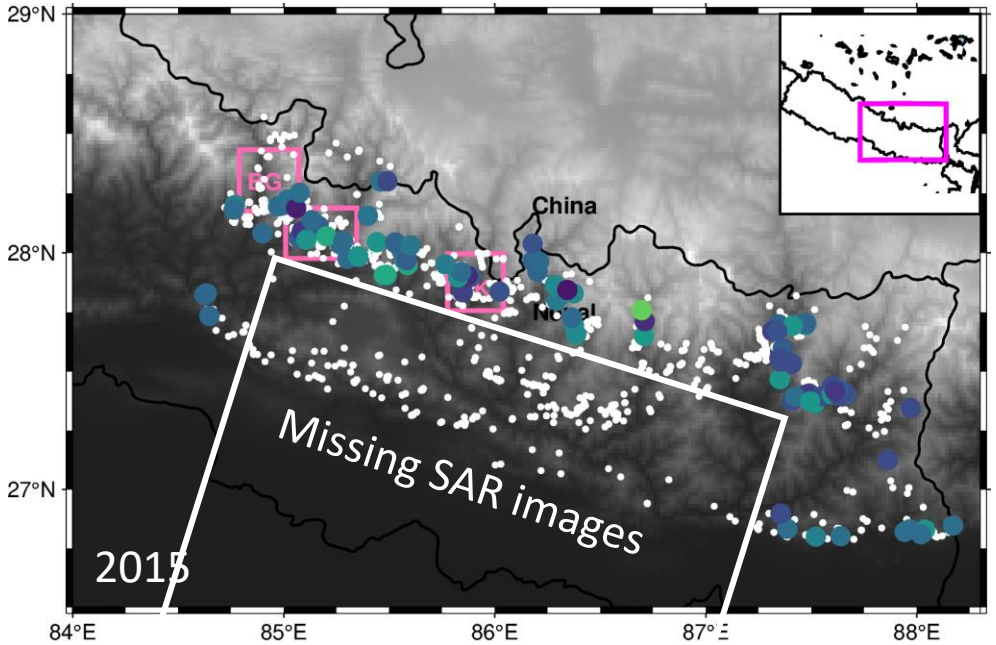


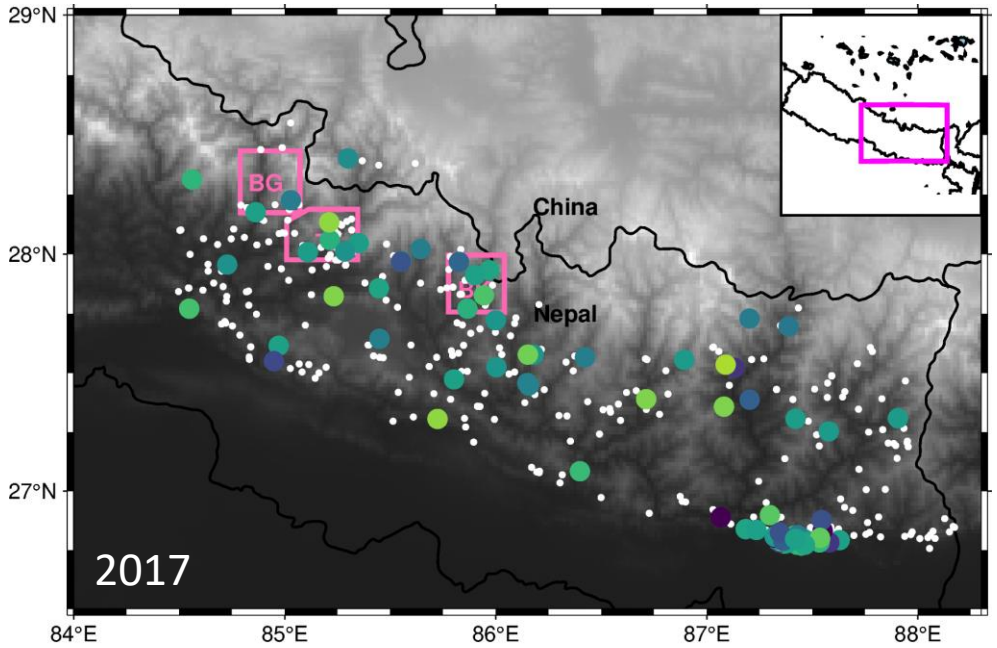
- Landslides result in a step change in these metrics – landslide timing obtained from detection of this step change.
- Methods tested on 3 inventories of landslides of known timing
- When a landslide is predicted the same date by at least 2 methods, this date is 80% likely to be correct
- From this, we can assign landslide timings for 20-30 % of the landslides

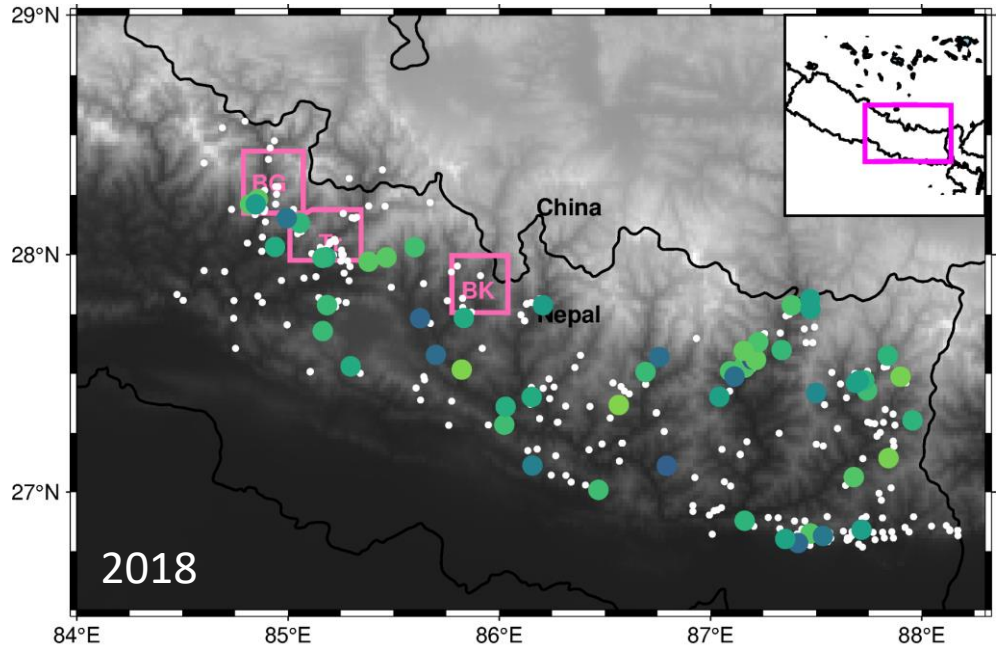
Burrows et al. (in review, NHESS)

White dots: landslides mapped my Jones et al. (2021)

Coloured dots: landslides timed using SAR methods





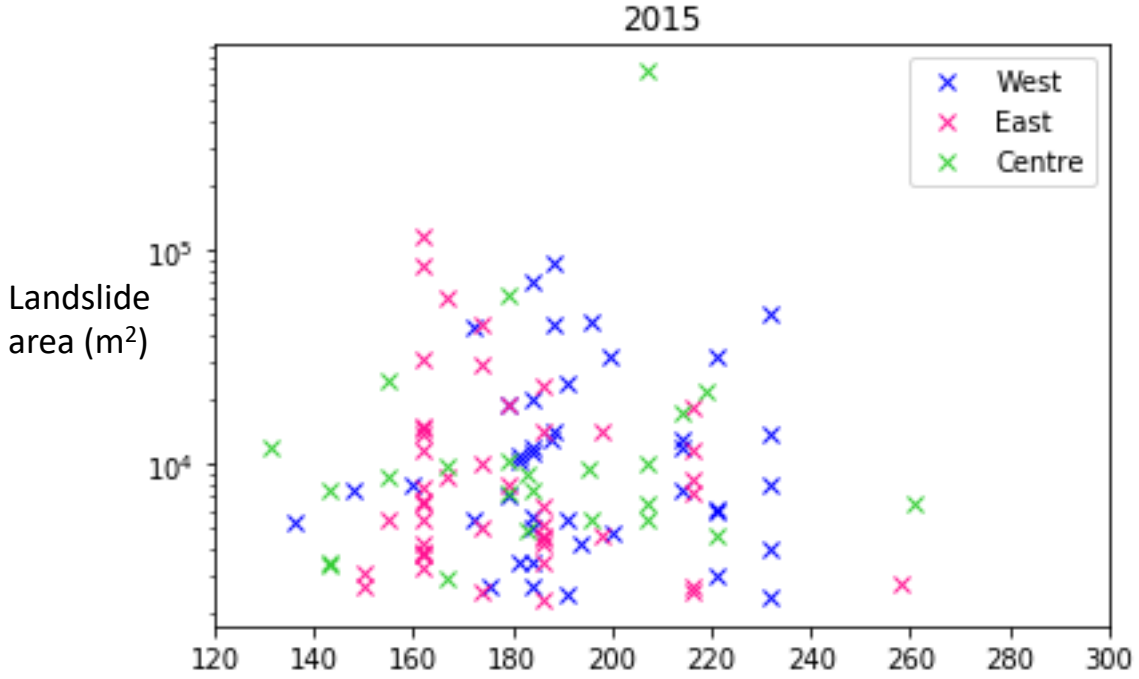


1st May — 31st Oct

150 200 250 300

Time (days)

- Application to annual inventories of Jones et al. (2021)
- Landslides occurred earlier in 2015 than in subsequent years



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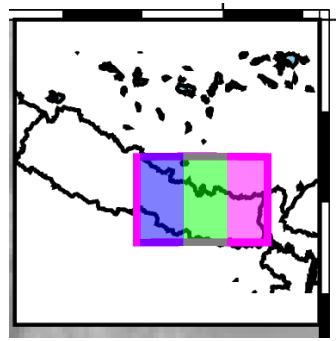
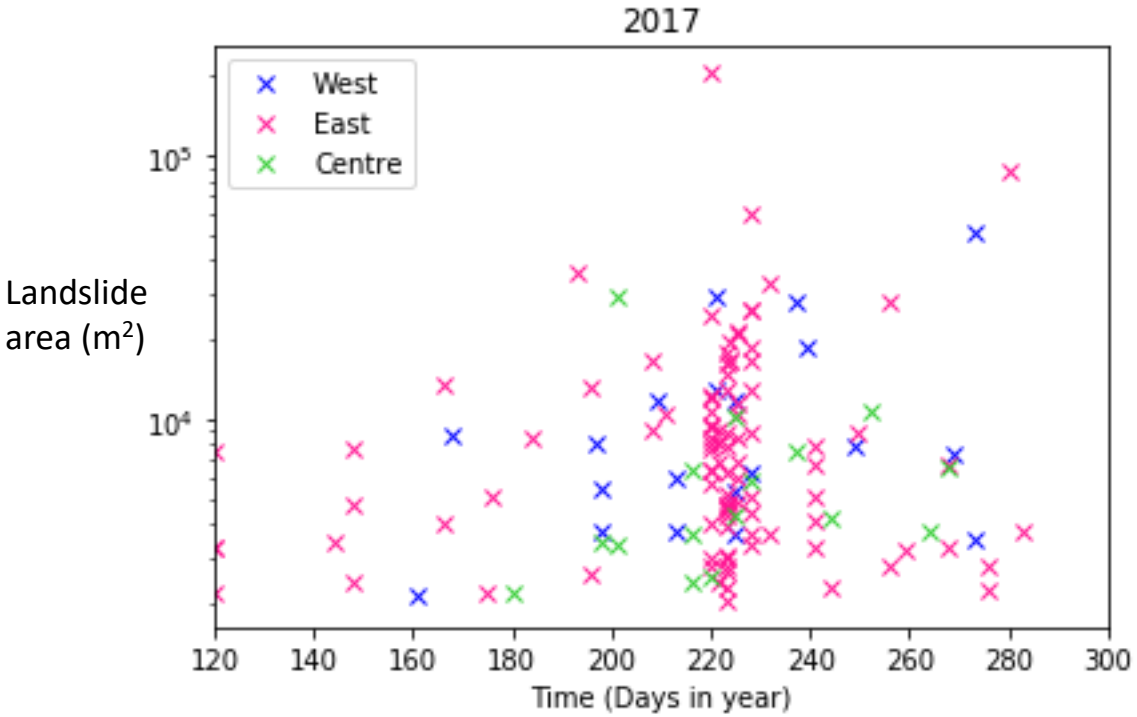
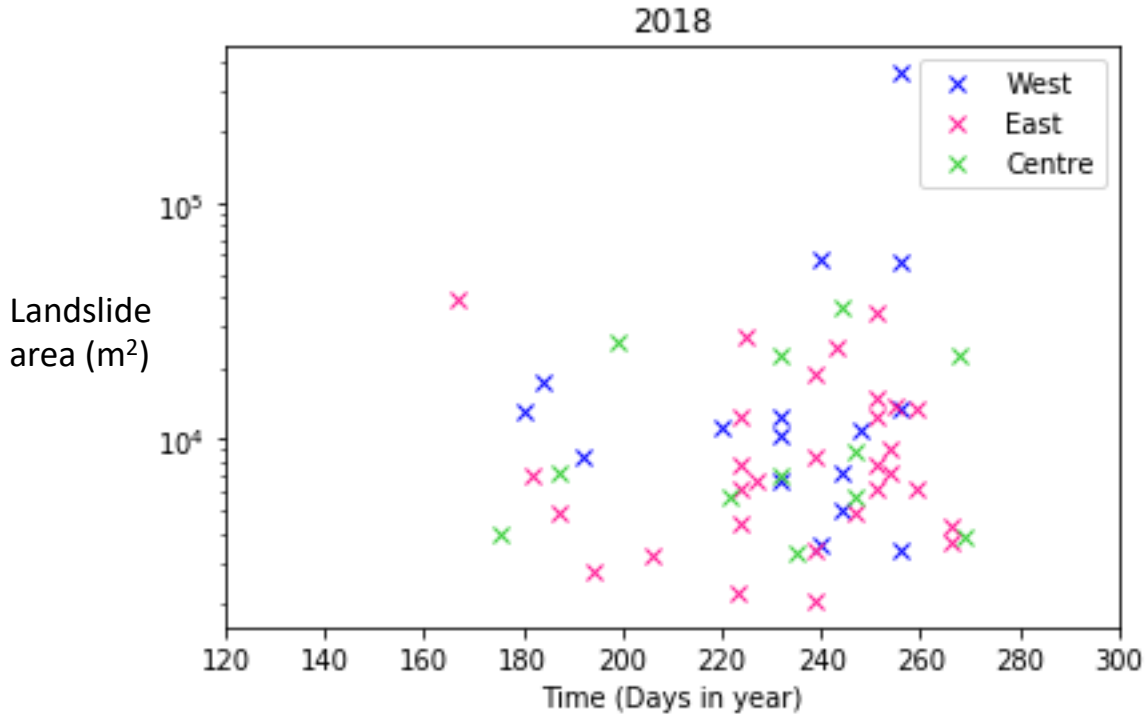
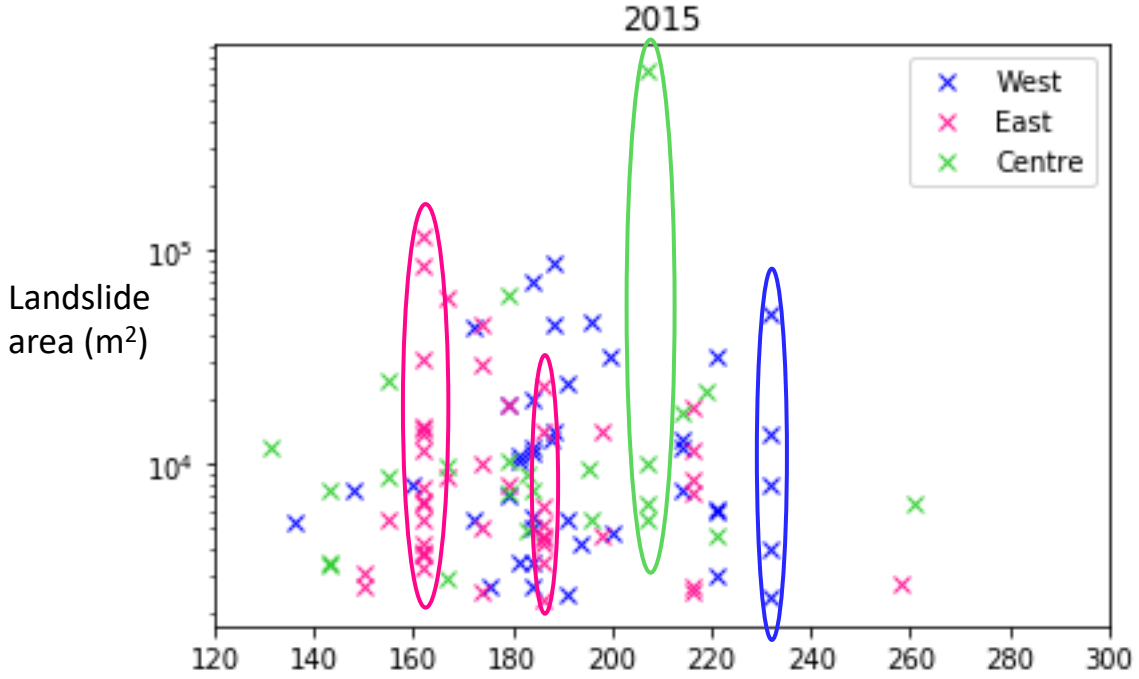
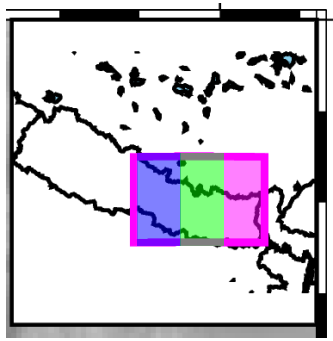


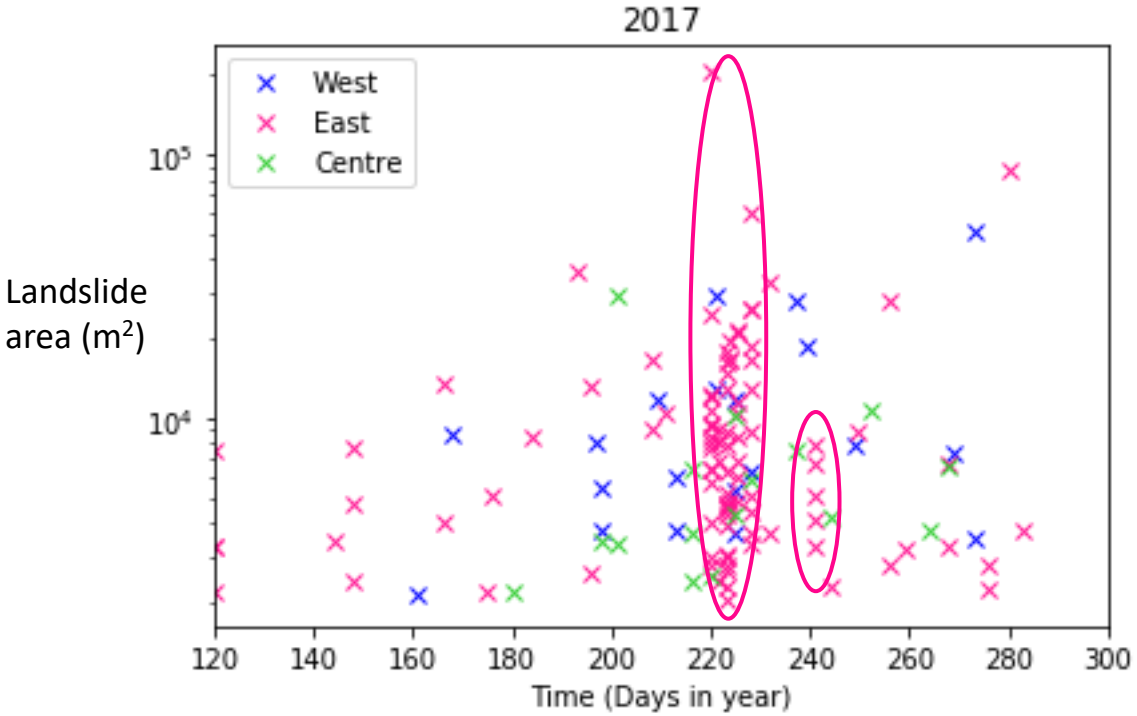


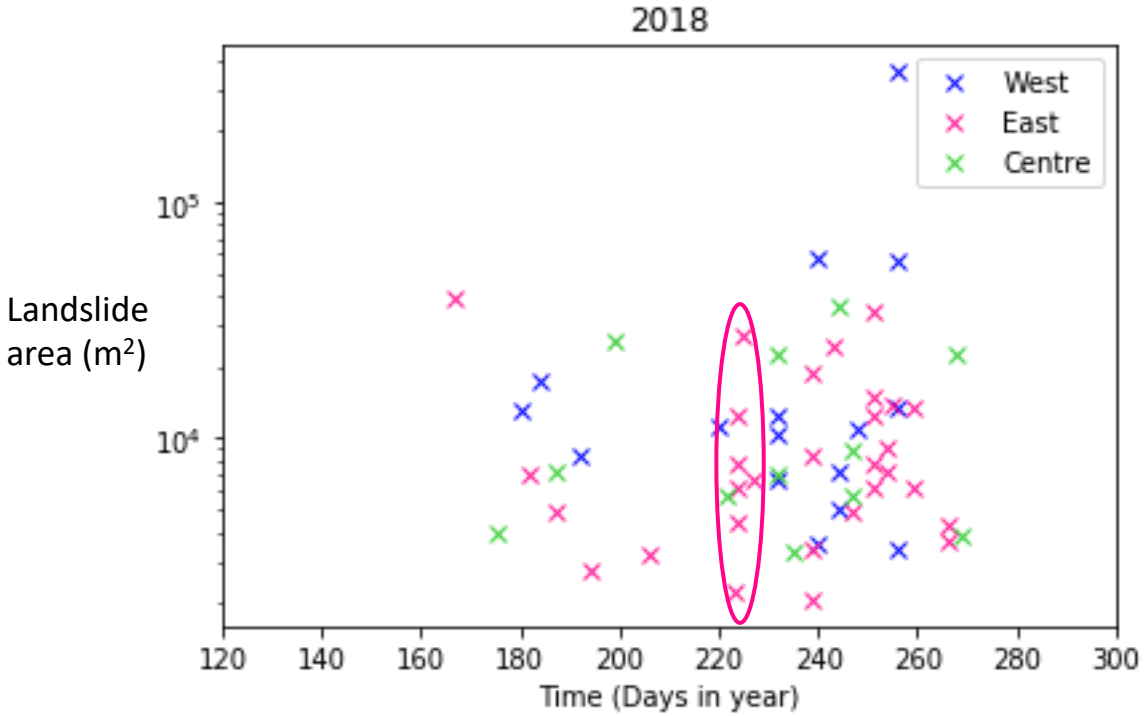


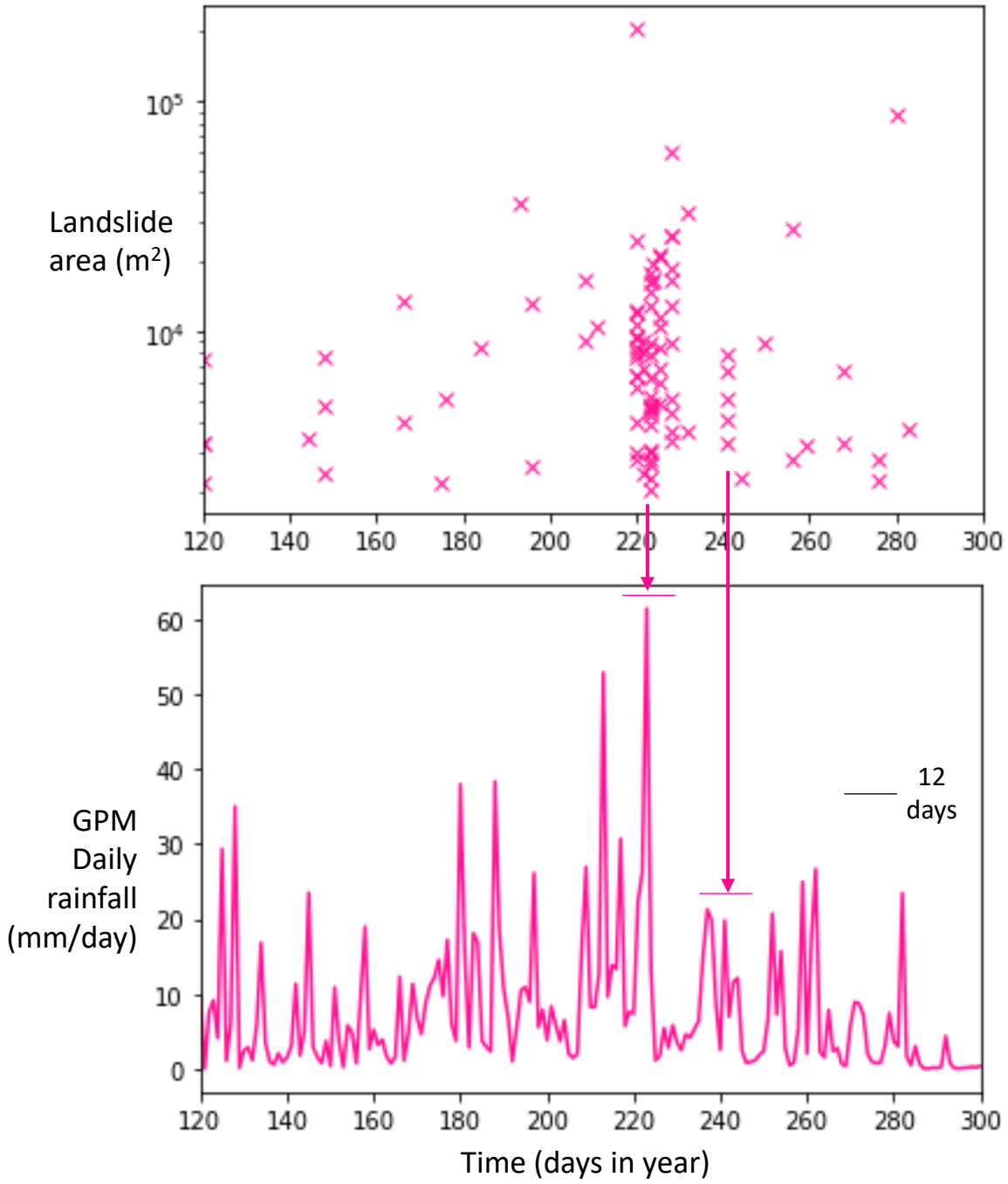


- Application to annual inventories of Jones et al. (2021)
- Landslides occurred earlier in 2015 than in subsequent years
- Visible spatio-temporal clusters of landslides

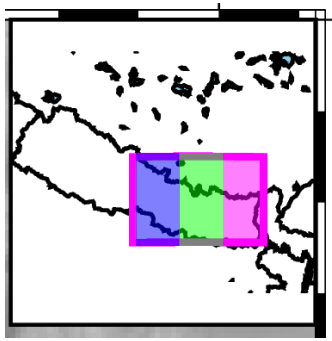






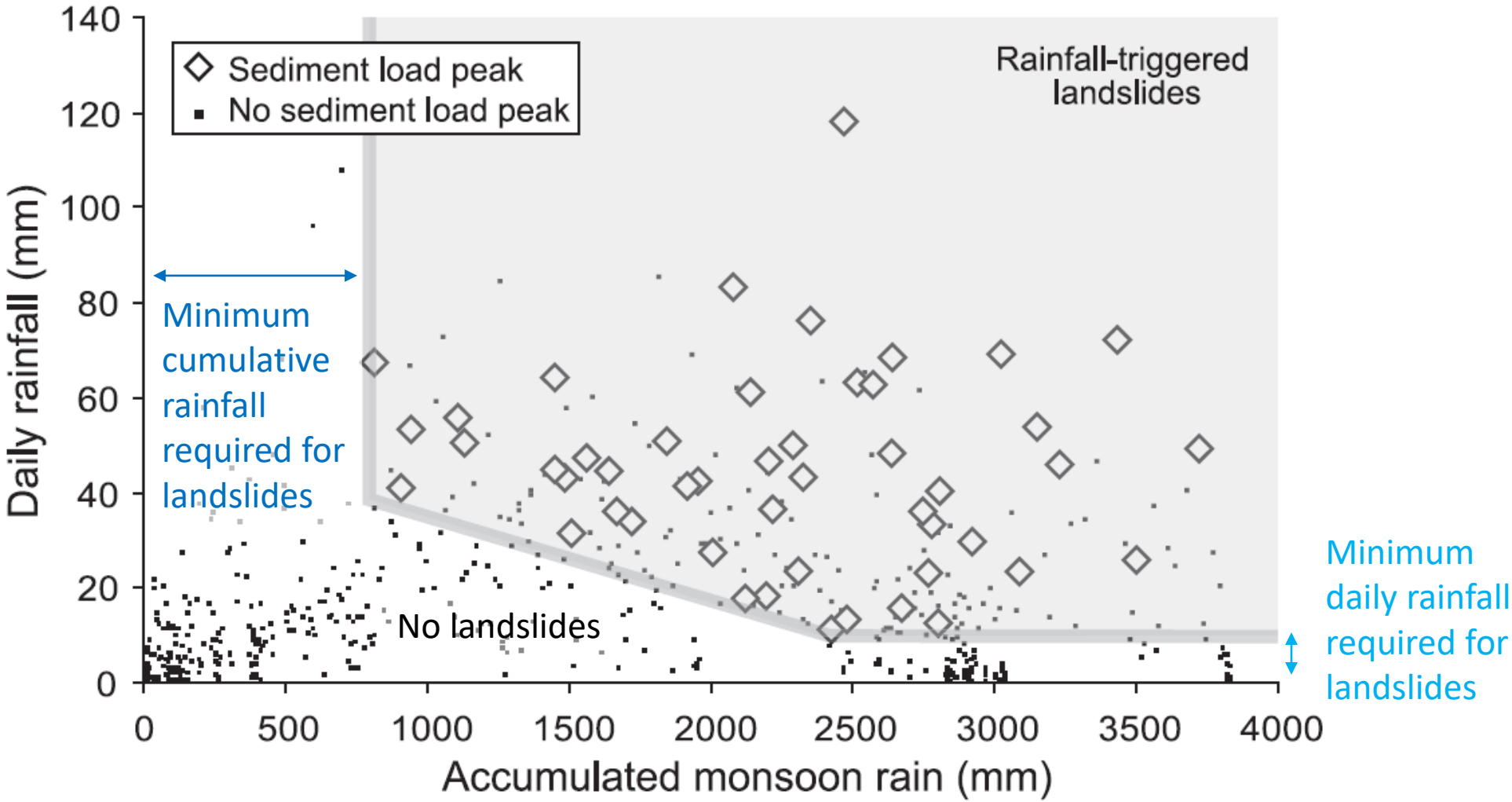


- Application to annual inventories of Jones et al. (2021)
- Landslides occurred earlier in 2015 than in subsequent years
- Visible spatio-temporal clusters of landslides
- Spatio-temporal clusters can be related to peaks in rainfall



(GPM satellite rainfall product)

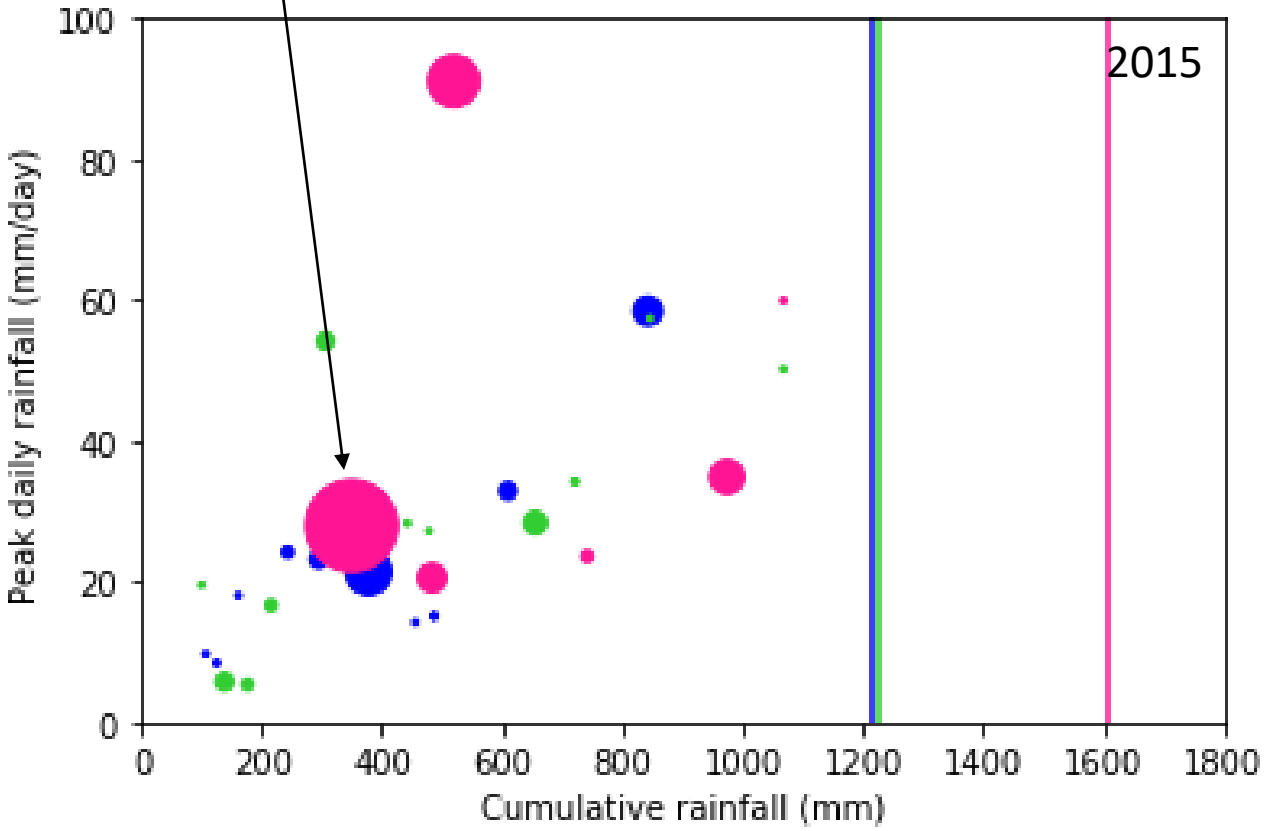
E.J. Gabet et al. / Geomorphology 63 (2004) 131–143



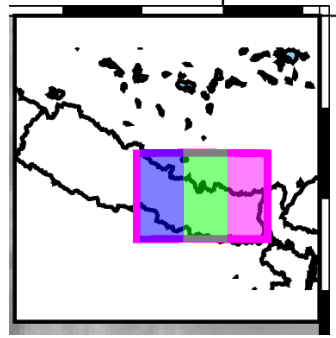
Gabet et al. (2004) : Landslides occur after a minimum cumulative monsoon rainfall **and** with a minimum peak in rainfall

Clusters occur after relatively little cumulative rainfall and for small peaks in daily rainfall (compared to 2017) – **weakened due to earthquake**

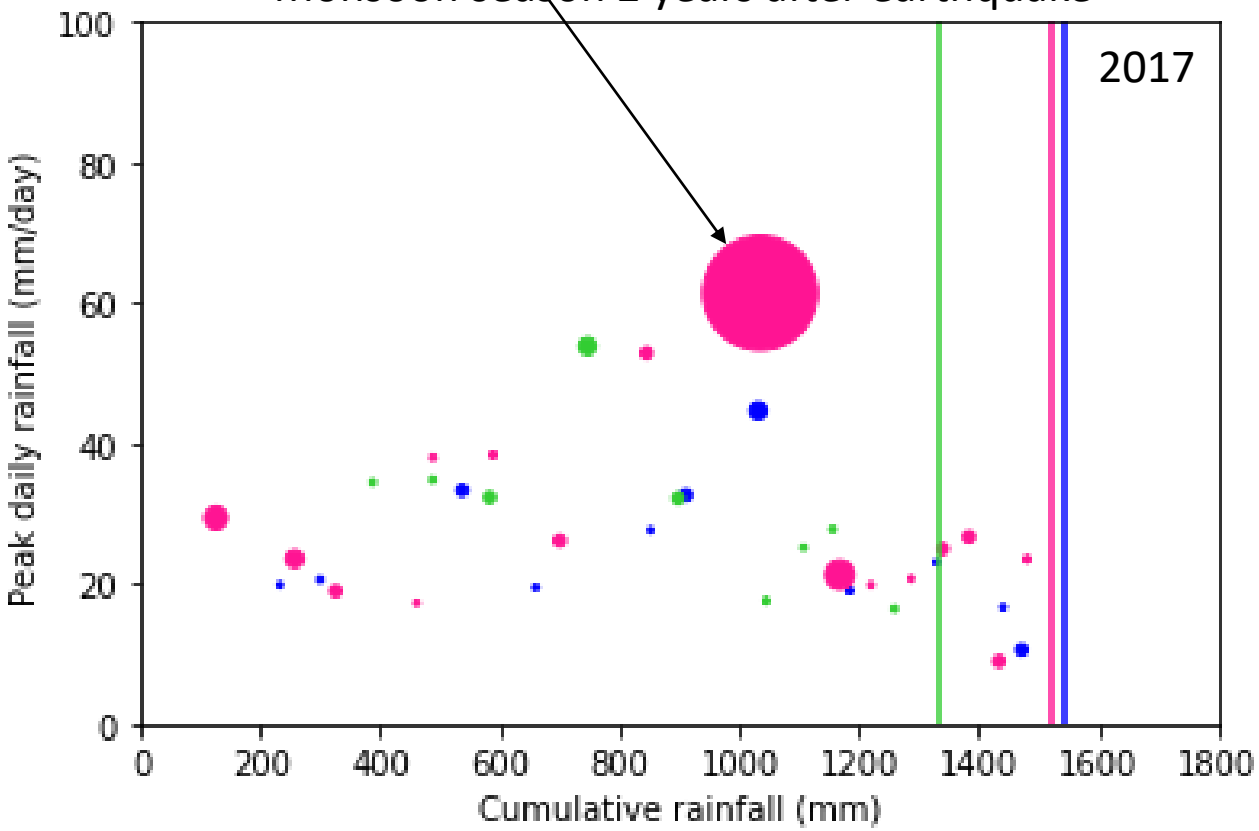
Post-seismic monsoon season



Cluster associated with strong peak in rainfall and after significant cumulative rainfall



Monsoon season 2 years after earthquake



Circle size = number of landslides in a cluster; Vertical lines = the cumulative rainfall reached by the end of the monsoon season

Conclusions

- We need both location and timing of landslides to associate them with specific triggering conditions during the monsoon
- Sentinel-1 amplitude time series can be used to assign ~12-day time windows to up to 30% of landslides in an inventory
- When applied to multi-annual inventories of the Nepal monsoon, we observe spatio-temporal clusters in landsliding
- Less rainfall (both peak and cumulative) was required for failure for the monsoon season following the 2015 earthquake

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References

For further information on the SAR-based landslide timing methods:

Burrows, K. Marc, O. and Remy, D. Establishing the timings of individual rainfall-triggered landslides using Sentinel-1 satellite radar data. In review. *NHESS Discussions.* https://doi.org/10.5194/nhess-2022-21

For further information on the multi-annual inventories of monsoon-triggered landslides:

Jones, J. N., Boulton, S. J., Stokes, M., Bennett, G. L., and Whitworth, M. R.: 30-year record of Himalaya mass-wasting reveals landscape 500 perturbations by extreme events, *Nature communications*, 12, 1–15, 2021.