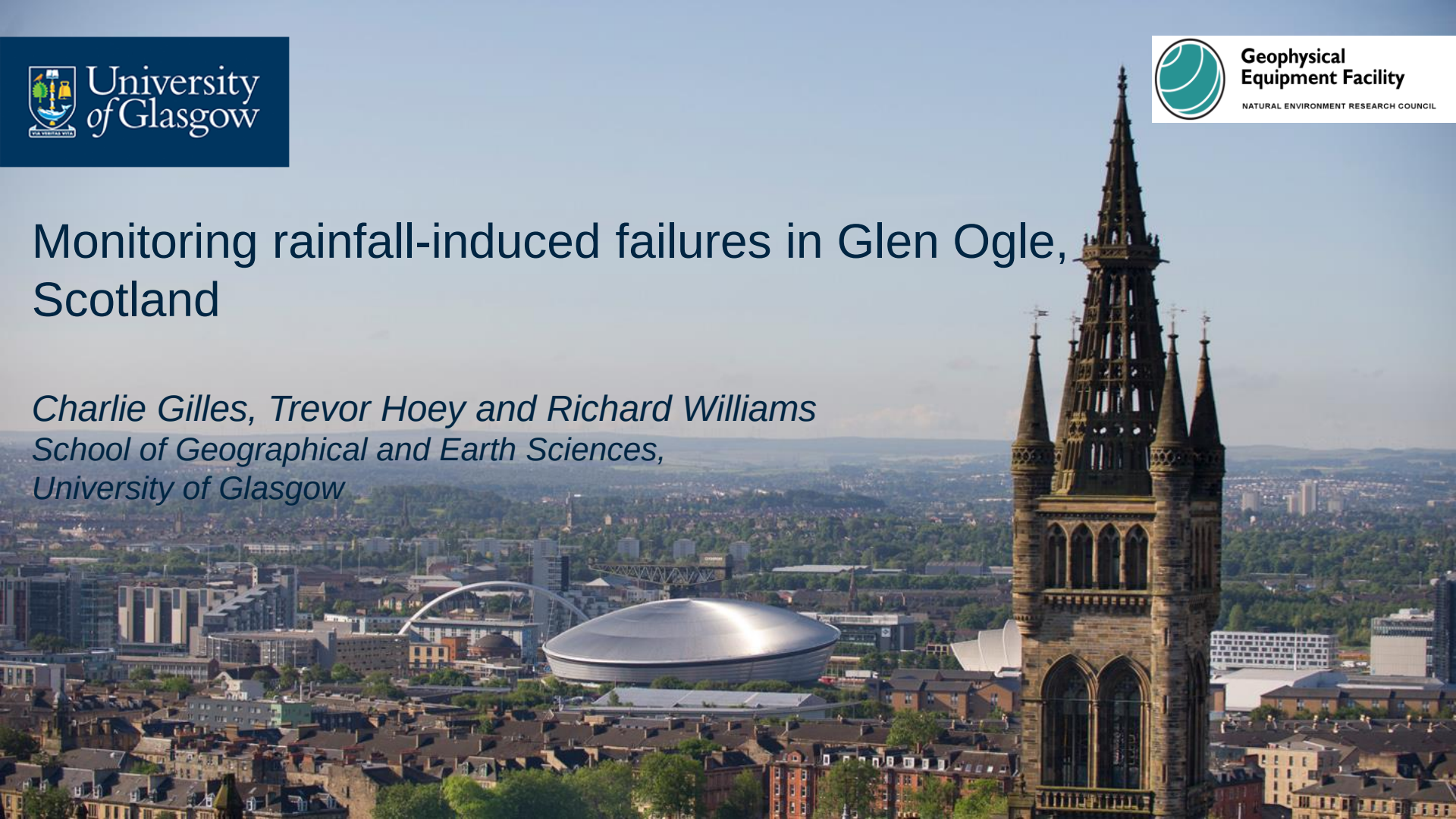

Monitoring rainfall-induced failures in Glen Ogle, Scotland

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Landslide impacts

- Costing globally $4 billion per annum
- > 16.5 k recorded in UK since 1970s
- 34% Scottish road network at risk

- Rest & Be Thankful
  - 2007
  - 2009
  - 2011
  - 2012
- Closure of A83
- Cost ~ £13.5 million in mitigation so far

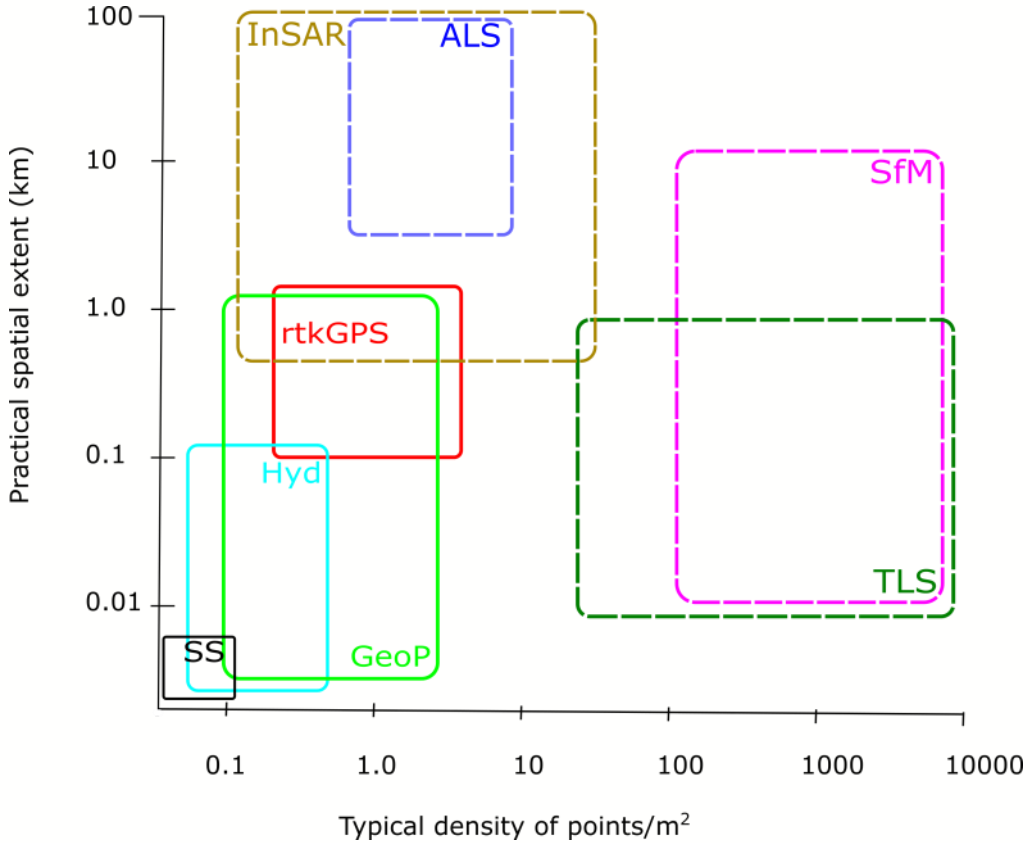
BGS

Landslide monitoring techniques

Coverage

- Regional – remote sensing (eg InSAR)
- Hillslope (eg TLS)
- Local (eg sensors)

Point density



Glen Ogle

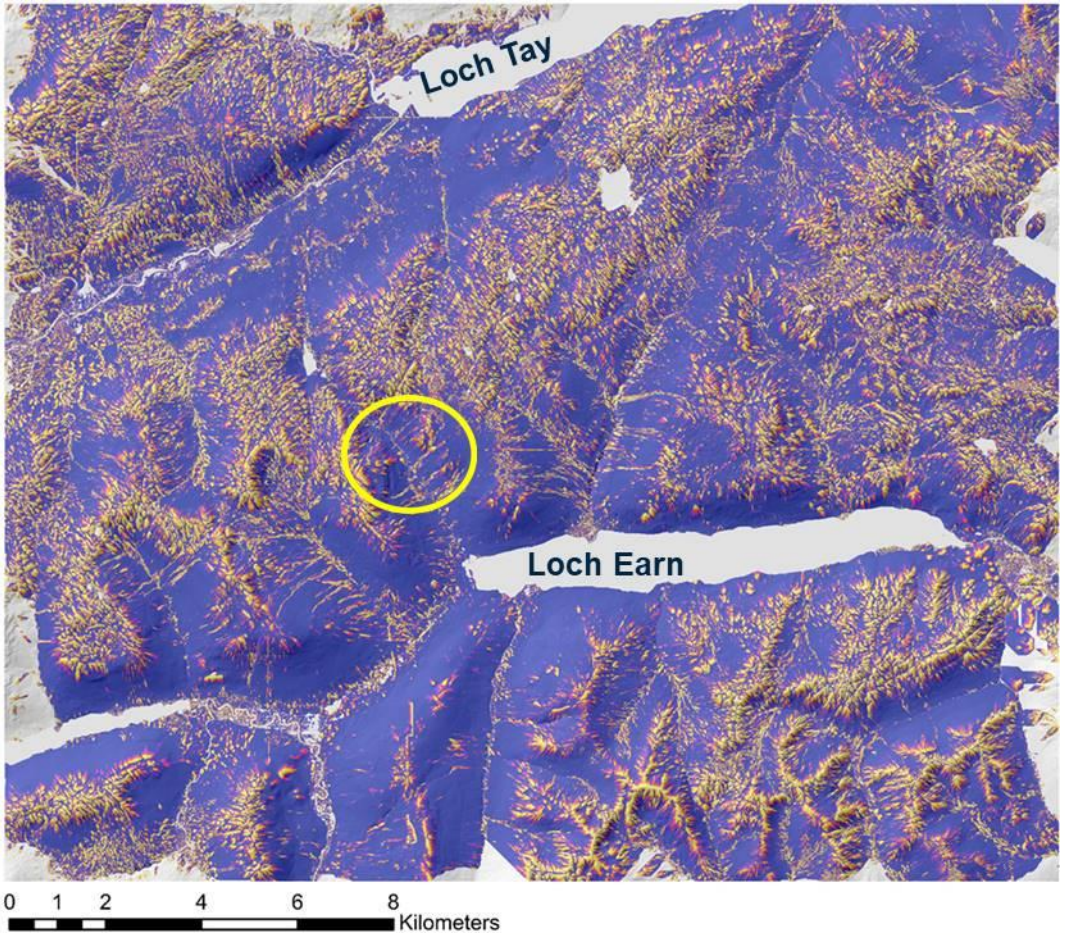
- 150 m asl valley floor
- Neighbouring peaks 600 m
- Mean slope 47^{0}
- Mean annual rainfall 1400 mm
- 18th August 2004- 80 mm of rain, peak intensity of 20 mm hr^{-1}
- In the preceding 10 days rainfall total 90 mm
- The 18^{th} August event generated 31 debris flows across Glen Ogle

Transport Scotland

Soil Saturation Index

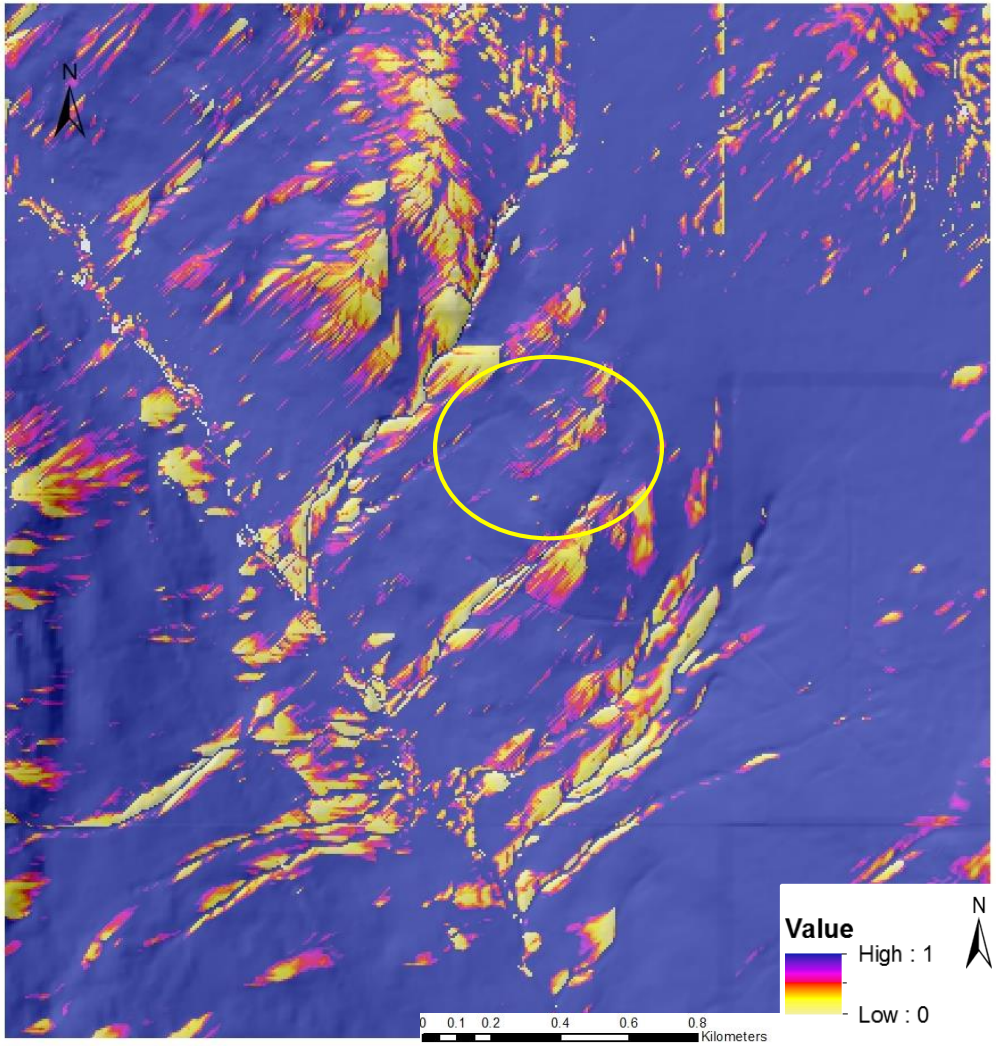
- Modelled soil saturation - effective precipitation 29 mm/day; uniform soil thickness = 1 m
- Saturated soils - purple

  unsaturated - yellow
- Glen Ogle - yellow circle
- O'Loughlin (1986)



Glen Ogle area

- SSI indicates areas of landslide susceptibility
- Study area in yellow circle

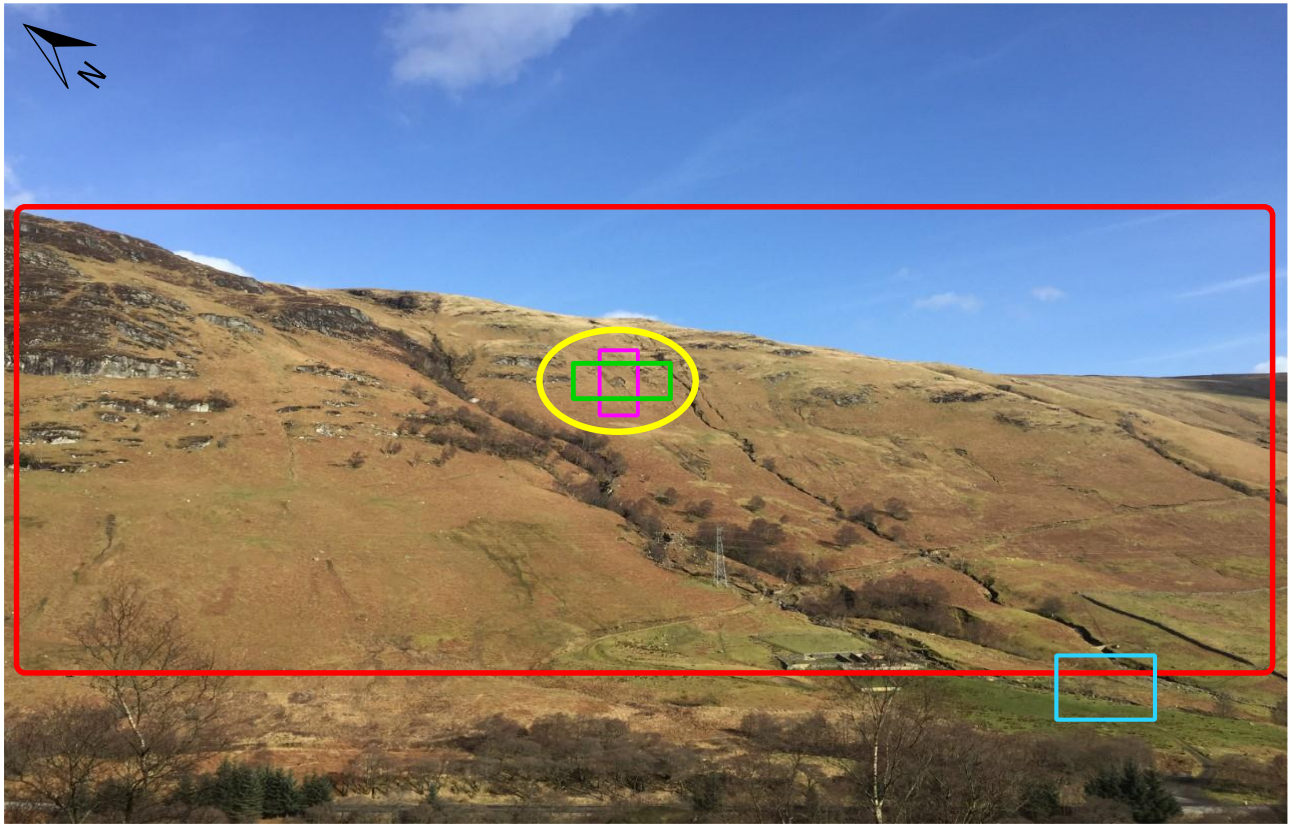


Geological setting

- Neoproterozoic bedrock, Ben Lui Schist formation (BGS)
- Overlain by Quaternary glacial deposits
- Diamict peat rich soil <2 m
- Some normal faulting

Methods

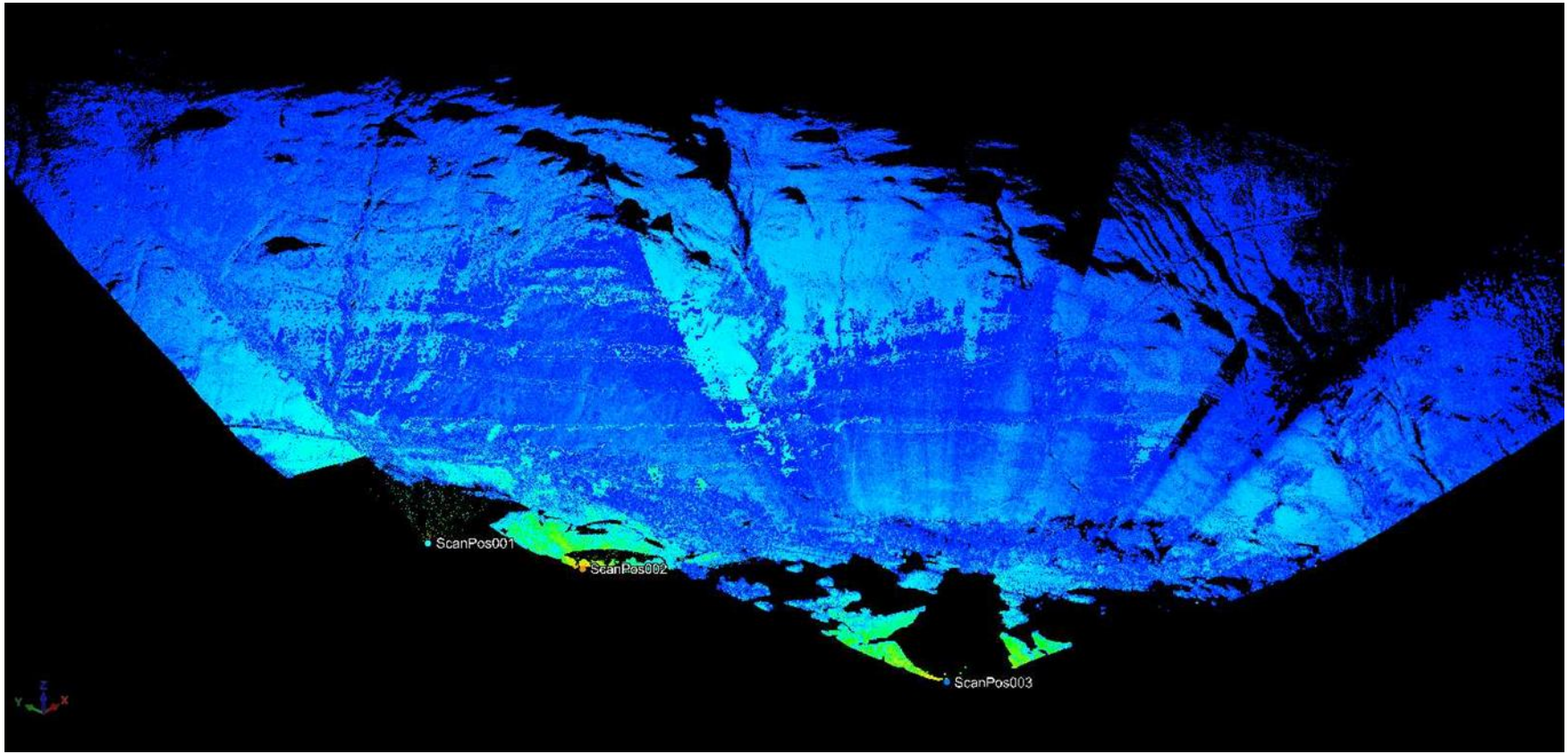
- Multi-sensor approach sensor network
- Area of interest (10 m by 15 m; failure and adjacent control slope) in yellow
- TLS
- Weather station
- IMU sensors
- Soil moisture probe.



TLS workflow

- 3 field campaigns October 2016-present
- Max scanning distance 1.4 km
- Field of view 3 km^2
- Three scanning positions
- Six 150 mm targets
- Targets and scan positions spaced over ~900 m
- Mean density 39 $points.m^{-2}$
- RMS error 0.28m

2016 raw merged point cloud (3km^2)



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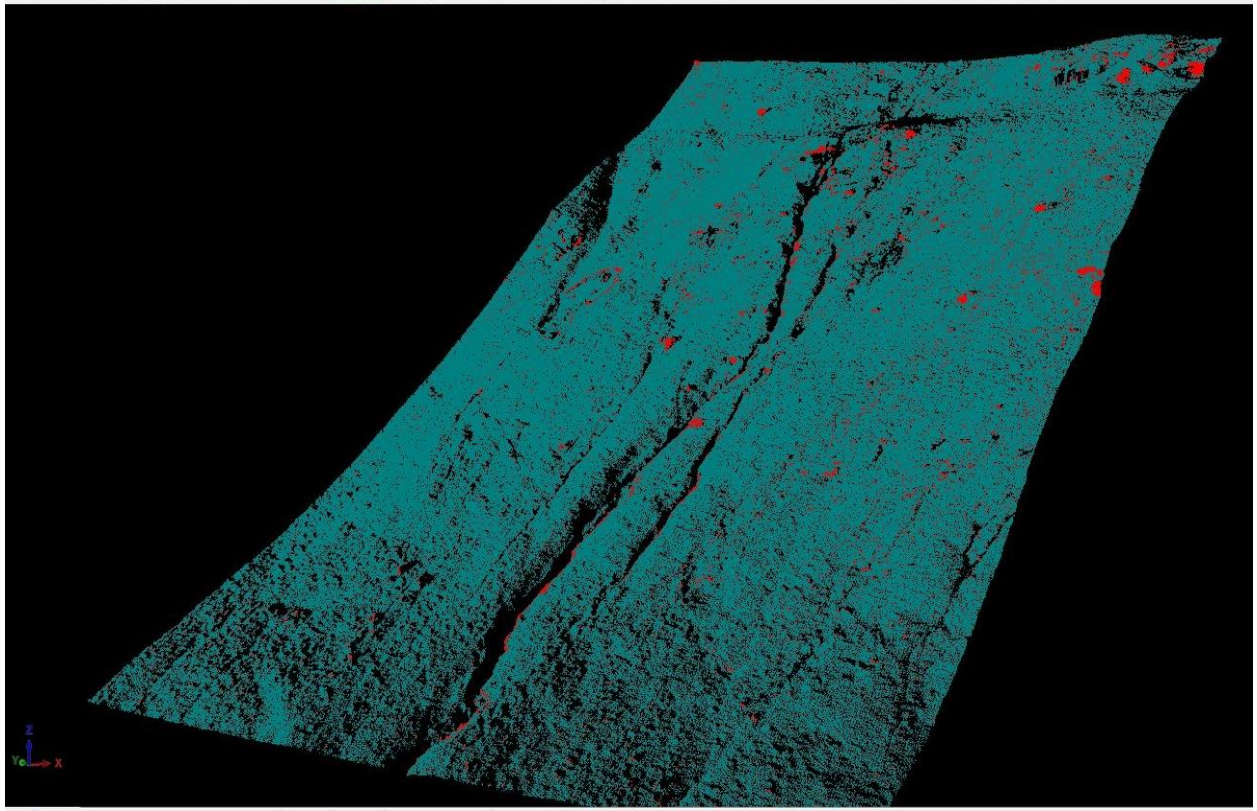
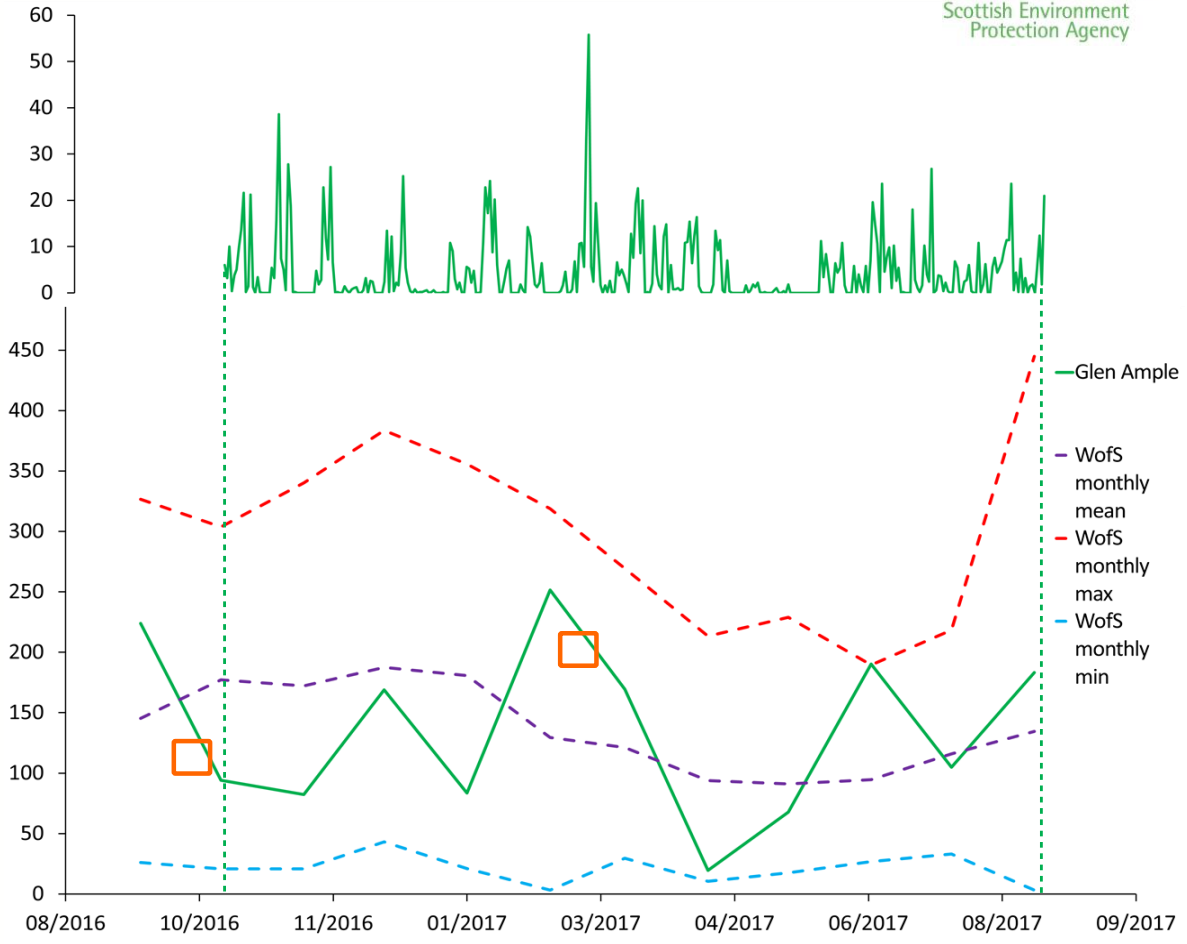


Rainfall Aug 2016 – Sept 2017

- Daily rainfall from SEPA weather station at Glen Ample (9 km from Glen Ogle)
- Monthly totals from SEPA data (green)
- Monthly maximum, minimum and mean (dashed lines) rainfall for West of Scotland (WofS), from Met Office data
- Orange boxes TLS scan dates



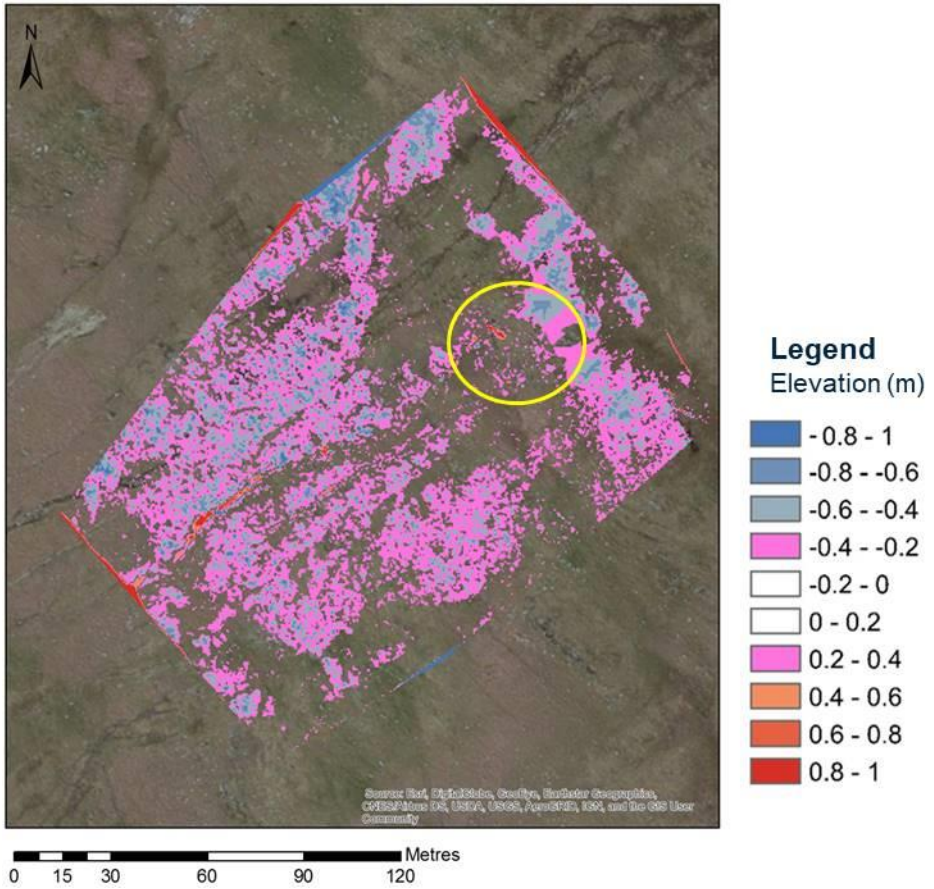
2016/17 DEM of Difference (DoD)

- Surface elevation change from October 2016 to March 2017

Blue- Sediment Loss.

Red- Sediment Gain.

No fill- negligible change



IMU sensors

- Wireless remote platform
- 3 axis accelerometer
  - +/- 4 g range
- Gyroscope
  - 200^0 s^{-1} sensitivity
- Nominal sampling frequency 50 Hz
- Specially designed aluminum housing
- Designed for high speed entrainment in rivers and coasts

IMU calibration

Artificial pebble sliding under gravity on a sand soil

Repeated 10 times recording data at each of:

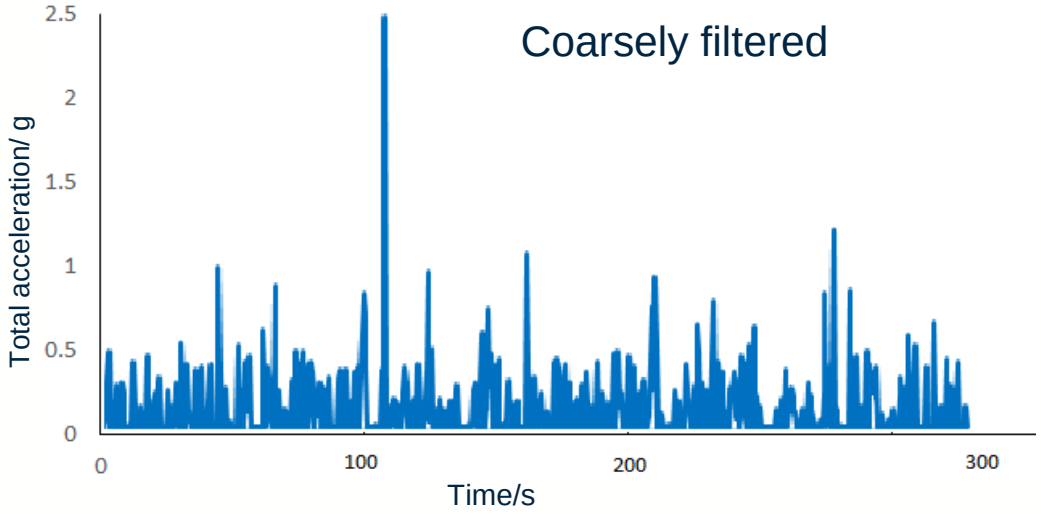
50 Hz

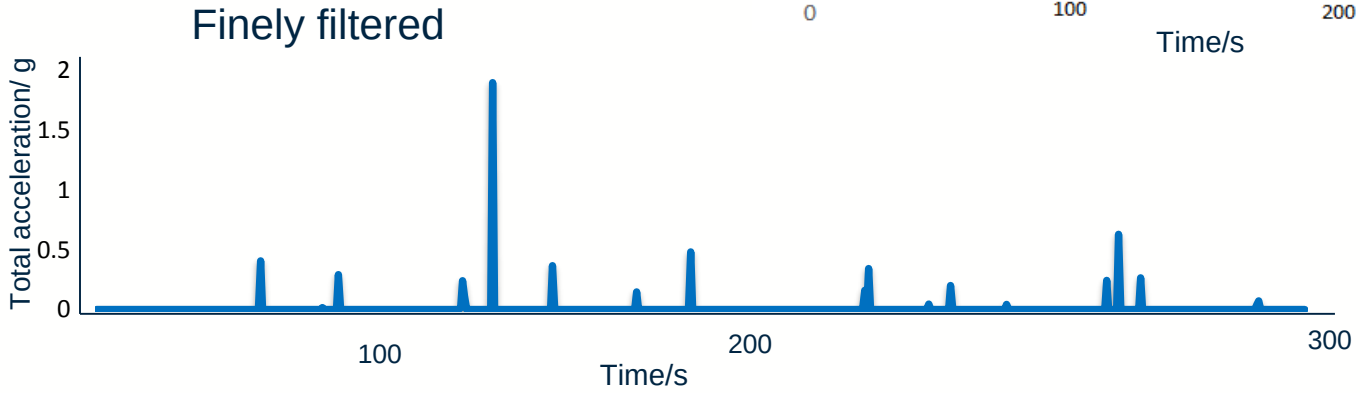
30 Hz

20 Hz

10 Hz

IMU 10 Hz data





Integrating methods

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Conclusions

- TLS method validated over a large spatial scale (1.5 km) with vertical errors of ± 0.28 m
- First DoD shows a maximum surface elevation change of ± 1 m
- Limited change in the DoD is due to an absence of large rainfall events between the scans
- DEM and SSI suggest how topography influences landslide susceptibility
- Sensor sampling at 10Hz identifies displacement events

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Thank you

@CharlieGilles1