Multi-scale analysis of landslide occurrence and evolution using remote sensing time series

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Remote sensing for landslide disaster management

Measures that prevent or reduce the impact of disasters (learning from the past) -> zoning of vulnerable, hazardous regions.

Prepare for next disaster: Monitoring of processes (indicators of next hazards) towards early warning.

Impact assessment contributing to coordinate cleaning up and rebuilding

Rapid impact assessment contributing to coordinate rescue efforts, first aid, evacuation.
Development of automated spatiotemporal landslide mapper

1 Pre-processing

- Metadata handling/homogenization
- Geometric Co-registration (relative & absolute)
- Conversion to TOA-Reflectance
- Masking of clouds and snow
- NDVI calculation

2 Construction of NDVI Time Series Data Cubes (TS)

- Tiling
- Resampling & stacking to TS
- Selection of bi-temporal data pairs

3 Landslide Identification

- Data
- Select
- Time

- A: bi-temporal (vegetation disturbance)
  - High is probability = high disturbance
  - Segmentation to LC
  - Date refinement, first occurrence of LC between pre and post.

- B: multi-temporal (post-failure revegetation)
  - High is probability = slow revegetation

- C: relief-oriented
  - DEM
  - Is probability in regard to:
    - slope
    - river network

Result: Multi-temporal Landslide Inventory

Landslide objects characterized by:
- Time of occurrence (between two acquisitions)
- Location and extent
- Overall likelihood being a landslide (based on 3A-C)
- Additional quantitative attributes (e.g., shape parameters)

Large-area landslide analysis in Southern Kyrgyzstan

Large area of intense and continuous landslide activity (>10,000km²)

High hazard and risk potential incl. fatalities

Big need for systematic spatiotemporal process analysis
Regular monitoring of spatiotemporal landslide occurrence

- Continuation of large-area monitoring using Sentinel-2 data (5 days revisit)
- Sentinel-2 global-scale availability of medium spatial (10-60 m) and spectral (12 bands) resolution free of charge
- Enables generation of multi-temporal landslide inventories at global scale

Retrospective analysis of backdated landslide activity

Southern Kyrgyzstan: 2500 km² study area
Analyzed time period: 1986 - 2013

- 250 optical satellite remote sensing data sets
  - Landsat, ASTER, Spot, RapidEye
- ~1500 landslides automatically detected
  - Size 100 sqm - 2.8 sqkm, 33.2 sqkm total area
  - clear differentiation between spatial hotspots of landslide activity and non-affected areas

Drone survey of selected landslides in Southern Kyrgyzstan
Equipment for drone surveys in Kyrgyzstan

Drone DJI Phantom 3/4 – Professional

**Drone (Quadcopter)**
- *max flight height:* 6000m NN, 500m above start point
- *distance ca.* 2km – rather short for long landslides
- *flight time:* 15-18min
- *flight speed:* asc. 5m/s desc 3m/s. horizontal: 16m/s

**Camera (RGB)**
- integrated (mounted on 3-axis gimbal)
- 12.4 M pixel (4000x3000) – JPG/DNG
- 4K Video – MP4/MOV
- 94° FOV (f2.8)

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Example Changet landslide – failure May 2015

Result of automated identification

Landslide
Length: 560 m
Area: 44200 m²

field photo taken in June 2015
Side-looking UAV image of Changet landslide, Kyrgyzstan – failure in May 2015, 5 victims
Drone survey in October 2016 by Robert Behling

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Multi-sensor and multi-scale analysis – Sogot area

- Pilot site for multi-sensor and multi-scale landslide monitoring
- High landslide risk; long-term constantly ongoing landslide activity

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Multi-temporal satellite remote sensing – Sogot area

Multi-temporal landslide occurrence detected from optical time series

1985/88: first activations
40 families were relocated

Break-up of Soviet Union:
uncontrolled resettlement

2003: 38 fatalities and
13 destroyed houses

Reactivations in 2004/15 caused no damage.

High likelihood for future destructive events

RE true color may 2016

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Multi-scale drone survey – Sogot landslide

Drone surveys

300m altitude:
2 flights, 205 images, 2.5 km²
-> complete area

150m altitude
1 flight, 171 images, 0.6 km²
-> landslide area

50m altitude
1 flight, 288 images, 0.1 km²
-> scarp, cracks

RE true color may 2016

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From drone survey to 3D model – 300m flight height

Agisoft Software

- Automatic tie point and dense point cloud generation
- Using dense point cloud to derive 3D mesh, DEM grid and ortho photo
- Takes hours to days (depends on image number and quality you chose)

Sogot: 300m altitude (terrain awareness), 205 images for 2.5km² (Low quality, 74K tie points, 3.5M point cloud)
DEM of ~1m pixel size and ortho photo of 12.4cm pixel size

Focus area of 150m flight height

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Sogot landslide – DEM overlaid by orthophotos
150m flight height

150m altitude (terrain awareness),
171 images for 0.6km² (medium quality, 74K tie points, 11.6M point cloud)
DEM: ~26cm pixel size, orthophoto: ~6.5cm pixel size

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Sogot landslide – 50m flight height for crack survey

New cracks evolved after 2015 failure, old cracks are reactivated (> 1m depth) – upslope progression of cracks behind main scarp including adjacent road area

Sogot: 50m altitude (terrain awareness), 205 images for 0.1km² (High quality, 97K tie points, 60M point cloud) DEM of ~4.9 cm pixel size and ortho photo of ~2.4 cm pixel size

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Multitemporal drone survey for crack monitoring

- 2016: new cracks evolved after 2015 failure, old cracks are reactivated (> 1m depth)
- 2017: cracks got wider and deeper - landslide prepares for next larger failure

Shaded relief representation of slopes derived from drone-based DEM's for enhancing cracks
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Comparison of co-seismic and monsoon-related landslide occurrence – 7.8 Mw Gorkha Earthquake

Nepal • Impact of earthquake (25 Apr 2015) • 2011-2016 period • RapidEye

Total detected landslides: 2300

Landslides related to slope units

Annual distribution of landslides

Pilot area 625km²: Upper Bhotekoshi region (Nepal) – Sensor: RapidEye - 6 years of data

Analysis of impact of earthquake (co-seismic landslide occurrence) on monsoon-related landslide activity including years before and after the 2015 earthquake

=> Increased monsoon-related landslide activity after earthquake due to substrate weakening

Behling et al. @ WLF4 - 2017

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Detection of co-seismic landslide occurrence – 7.8 Mw Kaikoura Earthquake (New Zealand)

New Zealand • Earthquake (14 Nov 2016) • 30,000km² analysis • Sentinel-2A

- 3 Sentinel-2 tiles before & after
- 17,637 landslides detected

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Credits: Canterbury Maps
Rapid response – detection of mass movements triggered by Mocoa intense rain/flood (Colombia)

Colombia • Intense rain fall /flooding (31 Mar 2017) • area 200km² • RapidEye

Heavy rain in NW South America (El Nino) Mocoa: 30 percent of monthly rainfall in one night => > 300 fatalities

More than 600 mass movements detected that occurred in the three watersheds draining to Mocoa.

Mass movements mobilized mud, boulders, debris which rushed through town of Mocoa.

Foto credits: crowdfunder.co.uk

Behling et al. @ International Disaster Charter - 2017
Identification of rainfall triggered landslides occurring in the North of Iran in April 2019 based on Sentinel-2

Identified landslide objects – For more details see Motagh et al. NH3.8: D1823 (10:45)
Summary

- **Developed automated landslide mapper**
  has proven to be applicable within different phases of disaster management cycle and for different landslide types occurring in varying natural environments and spatial scales

- **Satellite remote sensing for large-area regular monitoring**
  - Satellite remote sensing data available for last ~30 years
  - Global satellite archives (Landsat, Sentinel-2) – free online access
  - Derivation of spatiotemporal process characteristics
  - Support for obtaining improved process understanding at regional scale

- **UAV for detailed surveys of selected landslide related phenomena**
  - High resolution monitoring of surface changes (e.g., erosion, sedimentation, slope activations – cracks, landslide failures)
  - Derivation of high-resolution DEM’s from dense point clouds also for volume change
  - Detailed 3-D visualization of relief and surface cover (orthophoto) – high resolution stereo data acquisition enables spatial match between relief and surface cover
  - Flexible on-demand data acquisition related to specific events and monitoring task

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References for remote sensing based landslide investigations conducted at GFZ

(1) Automated spatiotemporal landslide mapper


Behling, R. and Roessner, S., 2017. Spatiotemporal landslide mapper for large areas using optical satellite time series data. In Mikos et al. (eds), Advancing Culture of Living with Landslides, Vol. 2 - Advances in Landslide Science, WLF 4 Ljubljana, Springer International Publishing, 143-152, DOI: 10.1007/978-3-319-53498-5_17


(2) Generation of multi-source landslide inventories in the context of susceptibility and hazard assessment


(3) InSAR-based landslide related deformation analysis in Southern Kyrgyzstan


Teshebaeva, K., 2016. SAR interferometry analysis of surface processes in the Pamir – Tien Shan active orogens - emphasis on coseismic deformation and landslides, PhD Thesis, Potsdam, University of Potsdam, 128 pp. https://publishup.uni-potsdam.de/opus4-ubp/frontdoor/index/index/docId/9874

Teshebaeva, K. Echtler, H., Bookhagen, B., Strecke, M., 2019. Deep-seated gravitational slope deformation (DSSGD) and slow-moving landslides in the southern Tien Shan Mountains: new insights from InSAR, tectonic and geomorphic analysis. Earth Surface Processes and Landforms, 44, 12, 2333-2348. DOI: 10.1002/esp.4648