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

Sigrid Roessner, Robert Behling, Mahdi Motagh &
Hans-Ulrich Wetzel

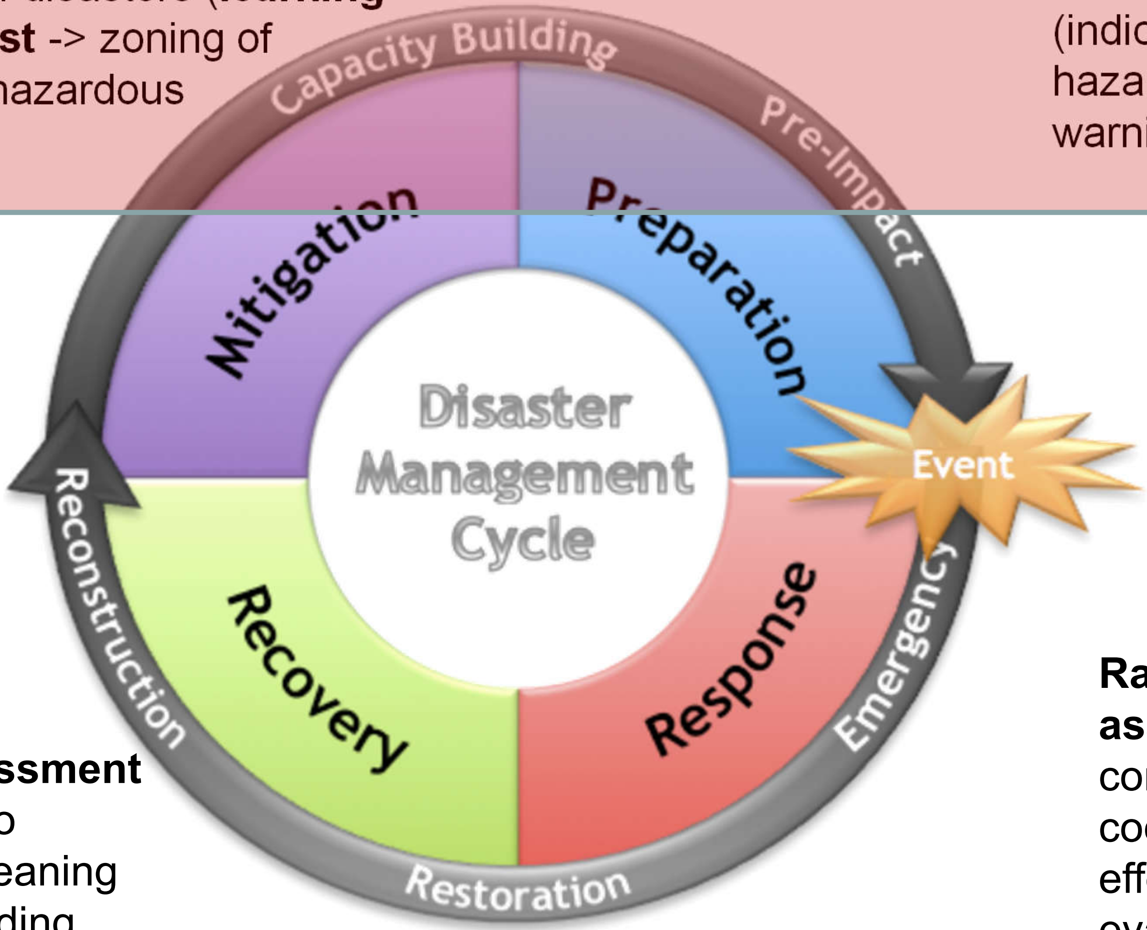
GFZ Potsdam, Section 1.4 – Remote Sensing and Geoinformatics
Contact: roessner@gfz-potsdam.de

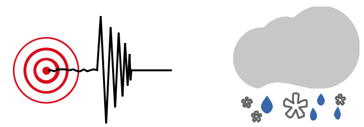
EGU 2020 Session NH3.8 – Wednesday 6 May, 8:30 – 10:15, D1809

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.





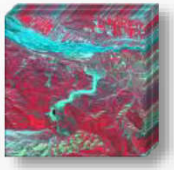
Impact assessment contributing to coordinate cleaning up and rebuilding

Rapid impact assessment contributing to coordinate rescue efforts, first aid, evacuation.

Development of automated spatiotemporal landslide mapper

1 Pre-processing

Input

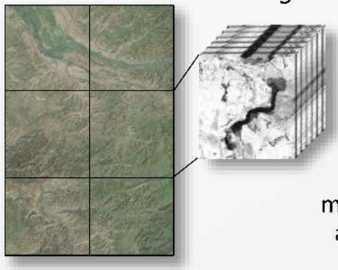


multi-sensor time series database

- *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*



time

data

select

most comp-arable in:
- sensor
- season
- short intervals
- spatial coverage
- acquisition properties

3 Landslide Identification

time

data

select

pre

post

post-failure

- *A: bi-temporal (vegetation disturbance)*

high ls probability = high disturbance

Segmentation to LC

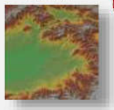
Date refinement. First occurrence of LC between pre and post.

- *B: multi-temporal (post-failure revegetation)*

high ls probability = slow revegetation

- *C: relief-oriented*

DEM



ls 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)

Behling et al. (2014) Automated Spatiotemporal Landslide Mapping over Large Areas Using RapidEye Time Series Data. *Remote Sensing*

Behling et al. (2016) Derivation of Long-Term Spatiotemporal Landslide Activity–A Multi-Sensor Time Series Approach. *Remote Sensing of Environment*

Behling, R., & Roessner, S., (2017). Spatiotemporal landslide mapper for large areas using optical satellite time series data, in: WLF 4. Springer International Publishing.

Large-area landslide analysis in Southern Kyrgyzstan

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

High hazard and risk potential incl. fatalities

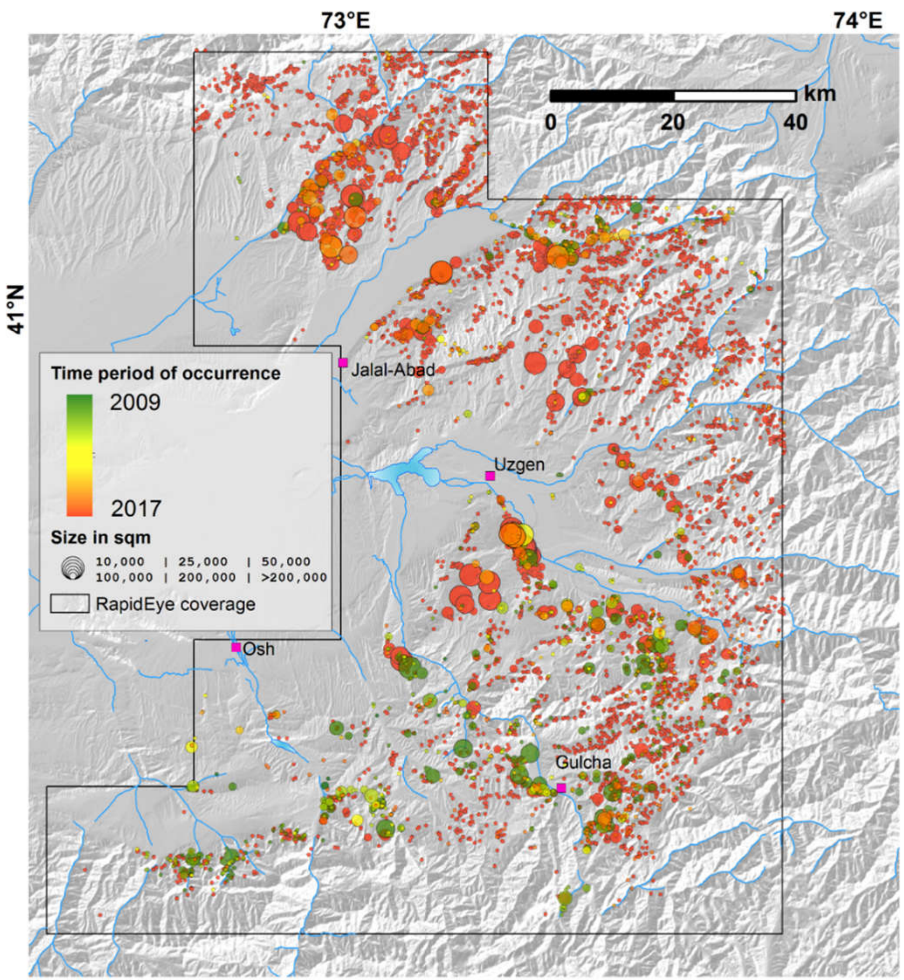
Big need for systematic spatiotemporal process analysis

2016

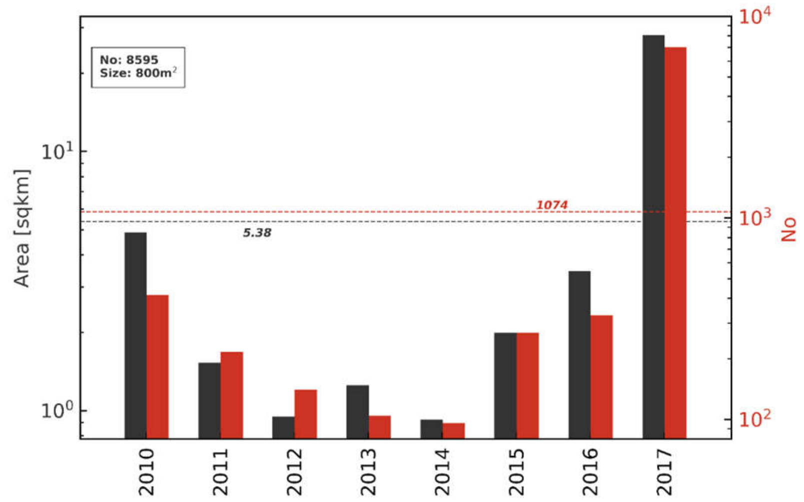
2010

2017

Regular monitoring of spatiotemporal landslide occurrence



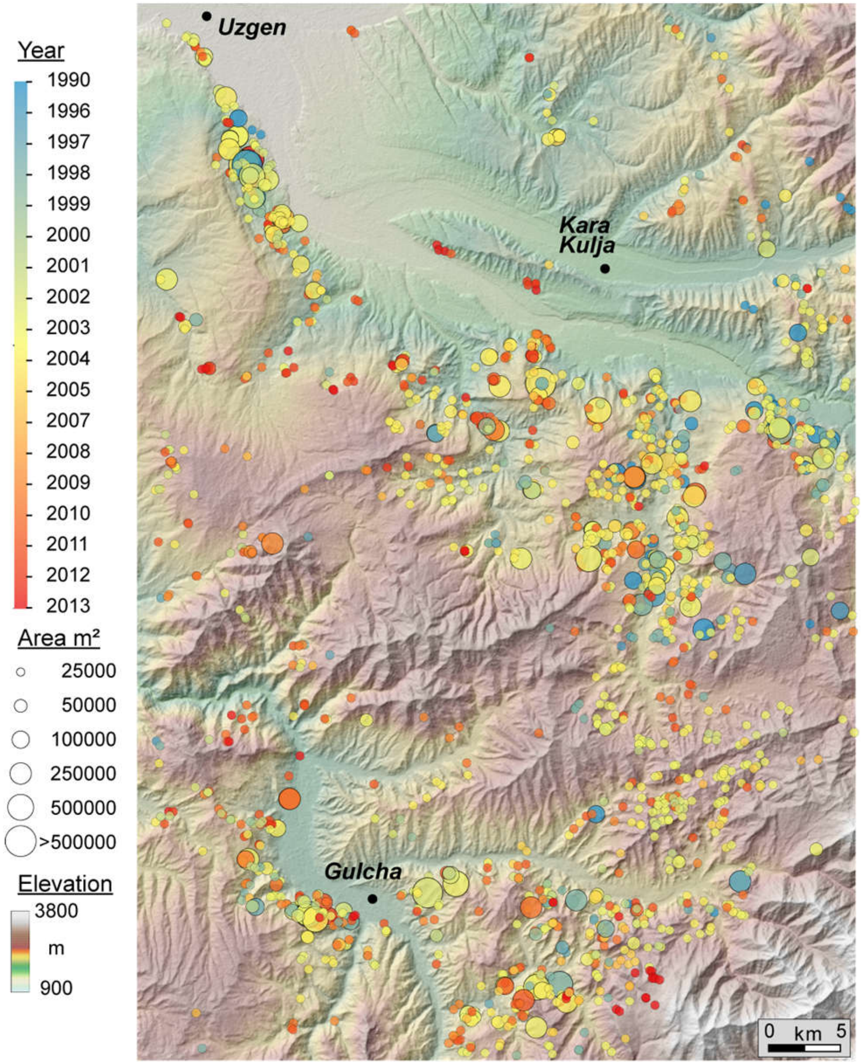
Southern Kyrgyzstan (12.000km²) - 8 years RapidEye



- 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

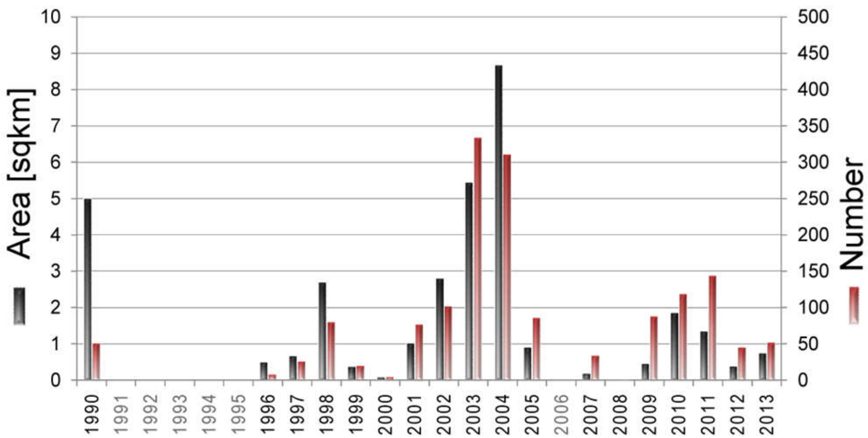
Behling, R. and Roessner, S. (2017): Spatiotemporal Landslide Mapper for Large Areas Using Optical Satellite Time Series Data. In: Mikos, M., Tiwari, B., Yin, Y., Sassa, K. (Eds.), Advancing Culture of Living with Landslides: Vol. 2 Advances n Landslide Science, Cham : Springer, pp. 143—152.

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



- annual average rate: No. 55, Area 1.2 sqkm
- temporal hotspot: 2003/04: 5 times average

Behling, R., Roessner, S., et al. , 2016. Derivation of long-term spatiotemporal landslide activity - multi-sensor time series approach. *Remote Sensing of Environment* 186, 88–104.

Drone survey of selected landslides in Southern Kyrgyzstan

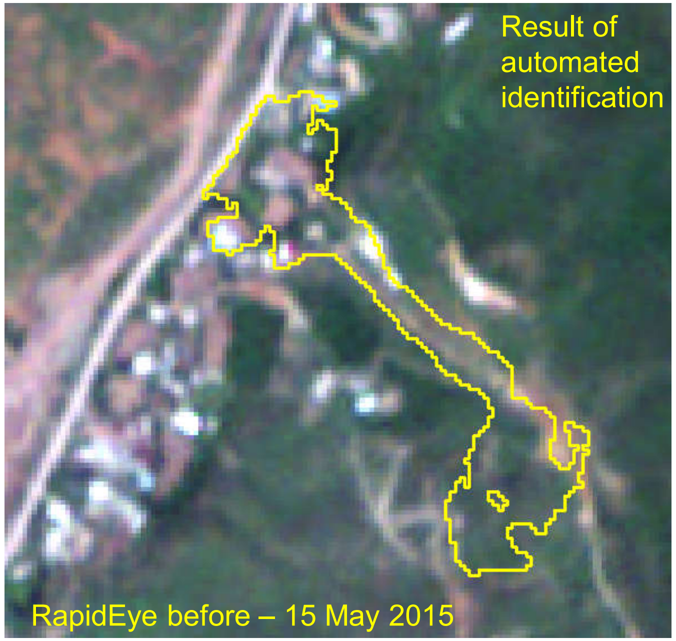
Equipment for drone surveys in Kyrgyzstan

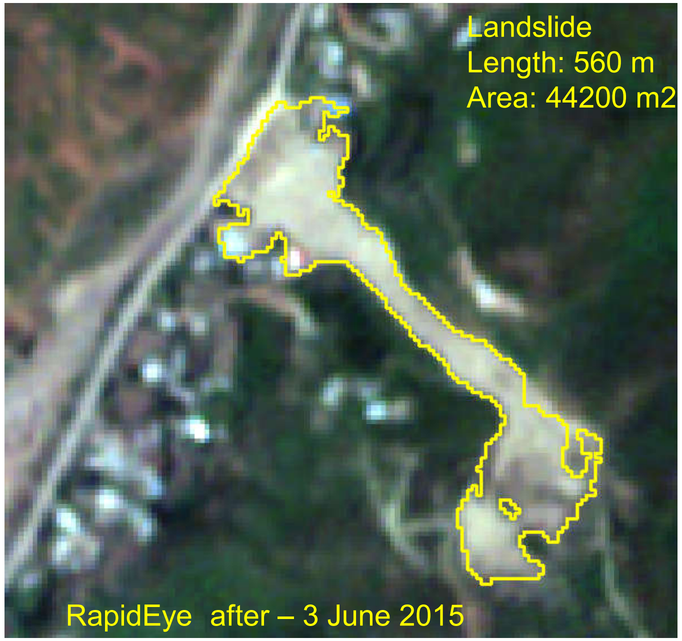
Drone DJI Phantom 3/4 – Professional

Drone (Quadcoptor)
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)

Example Changet landslide – failure May 2015

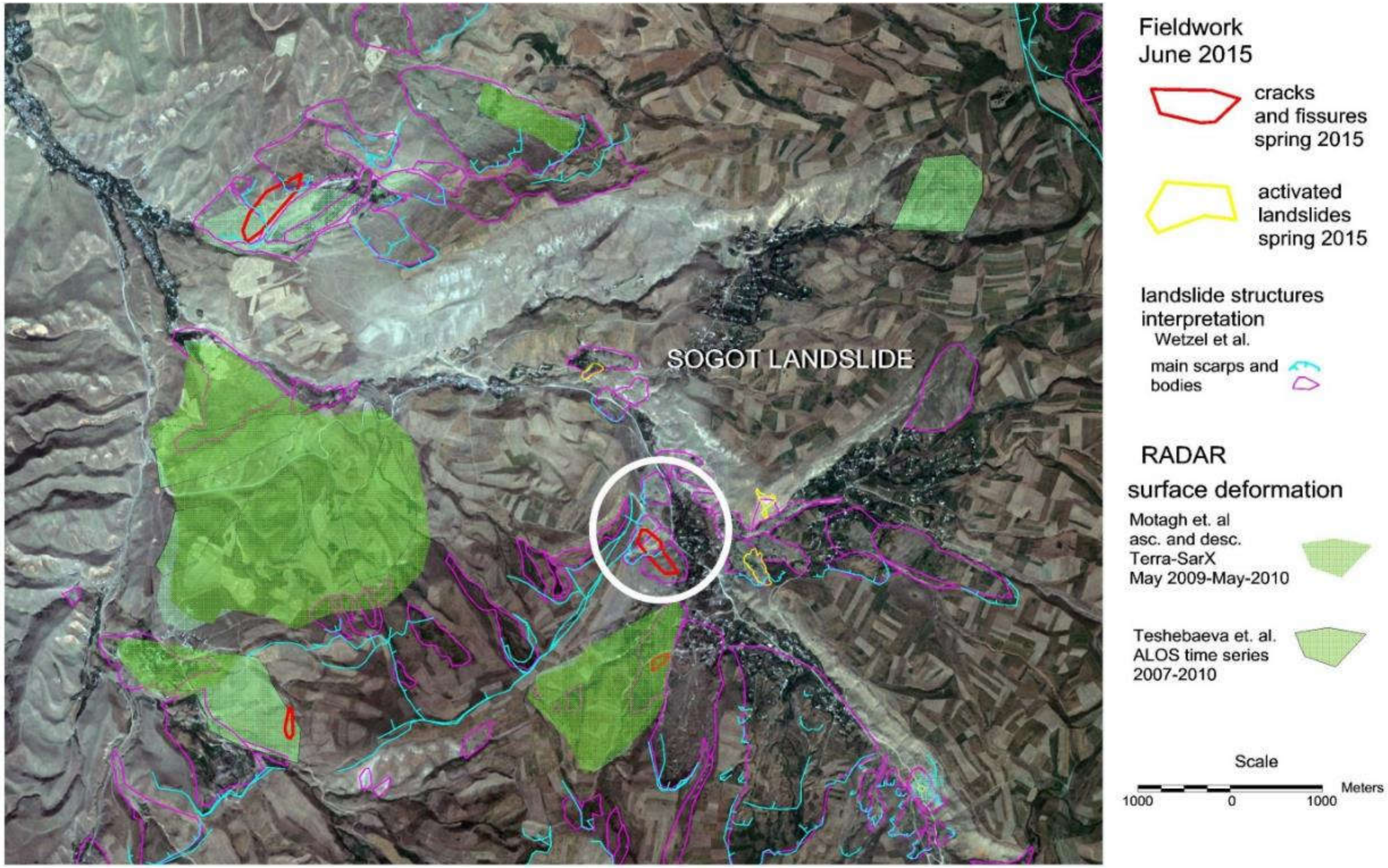




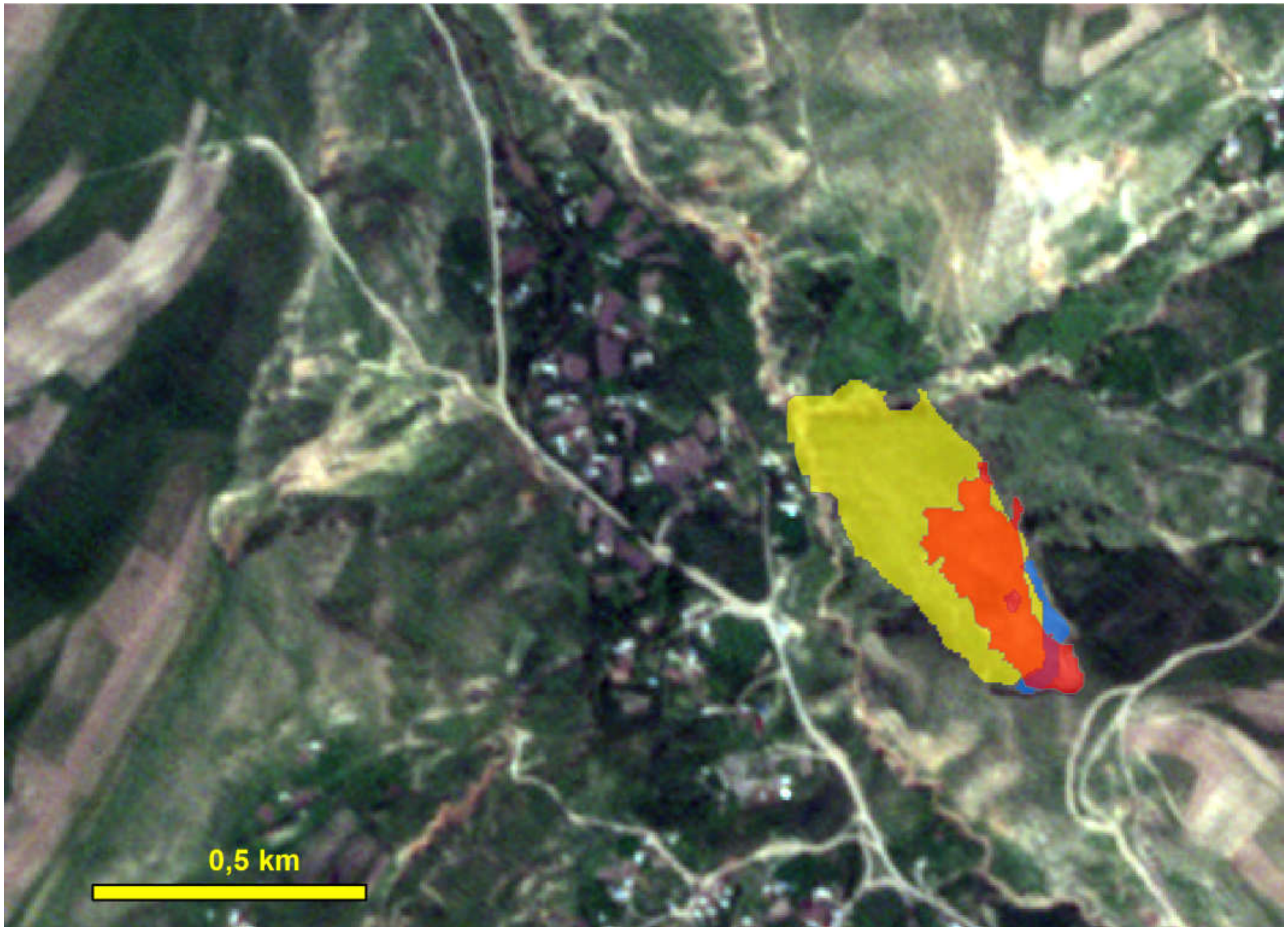
Side-looking UAV image of Changet landslide, Kyrgyzstan – failiure in May 2015, 5 victims
Drone survey in October 2016 by Robert Behling

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



Multitemporal satellite remote sensing – Sogot area



RE true color may 2016

landslide activations
2003 , 2004, 2015

Multi-temporal landslide occurrence detected from optical time series

1985/88: first activations
40 families were relocated

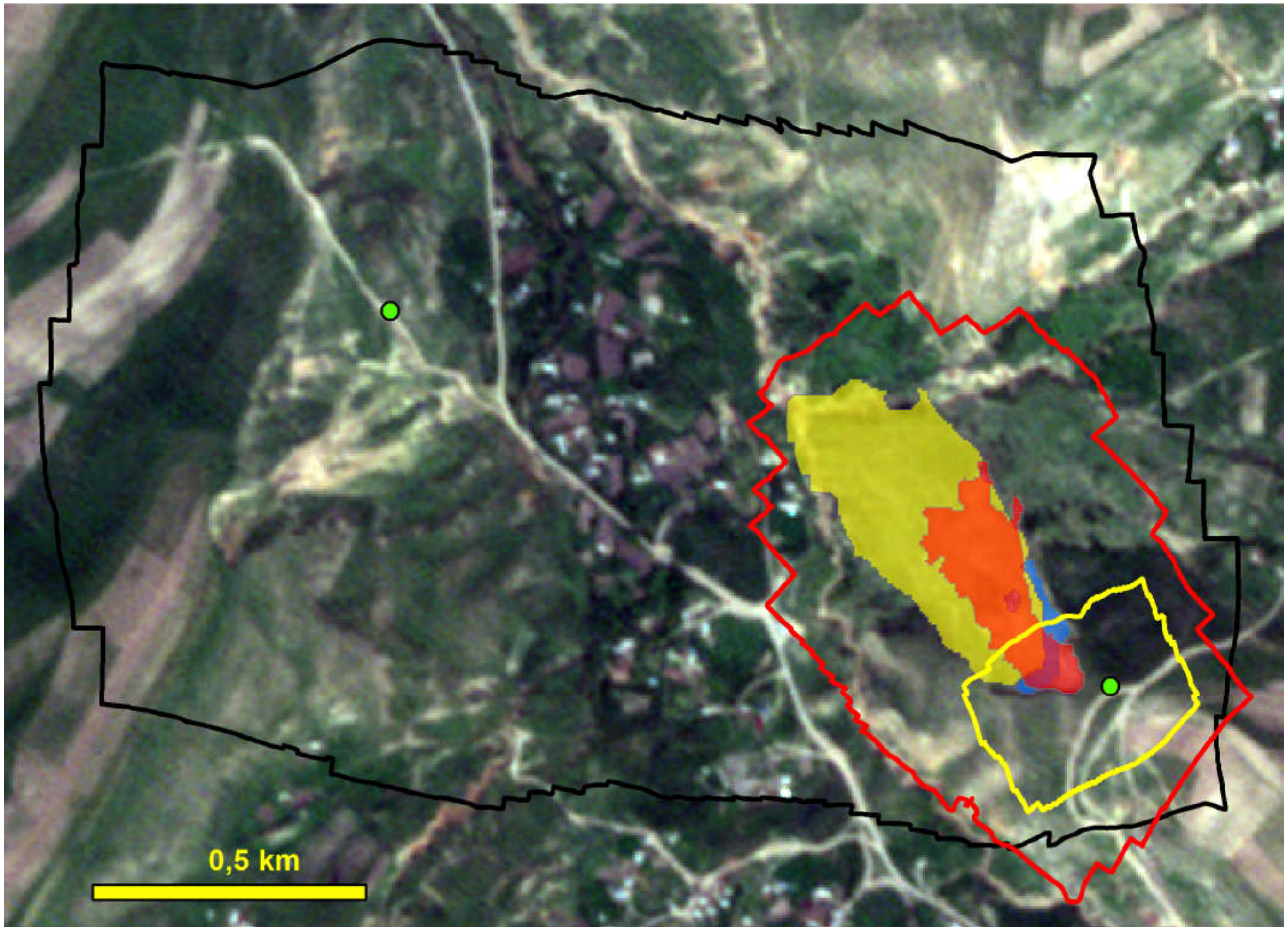
Break-up of Soviet Union: uncontrolled resettlement

2003: 38 fatalities and
13 destroyed houses

Reactivations in 2004/15 caused no damage.

High likelihood for future destructive events

Multi-scale drone survey – Sogot landslide



RE true color may 2016

<u>Drone surveys</u>

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

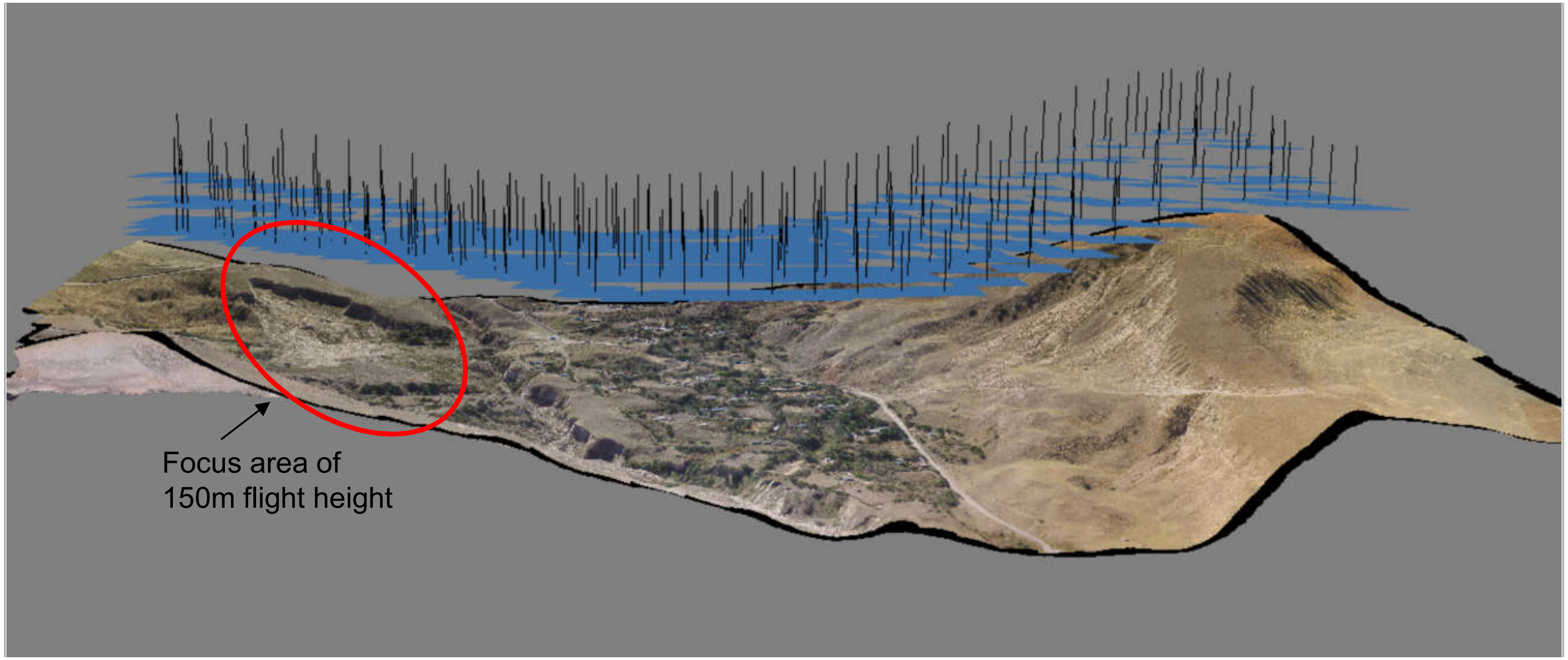
150m altitude
1 flight, 171 images,
0.6 km²
-> landslide area

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

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

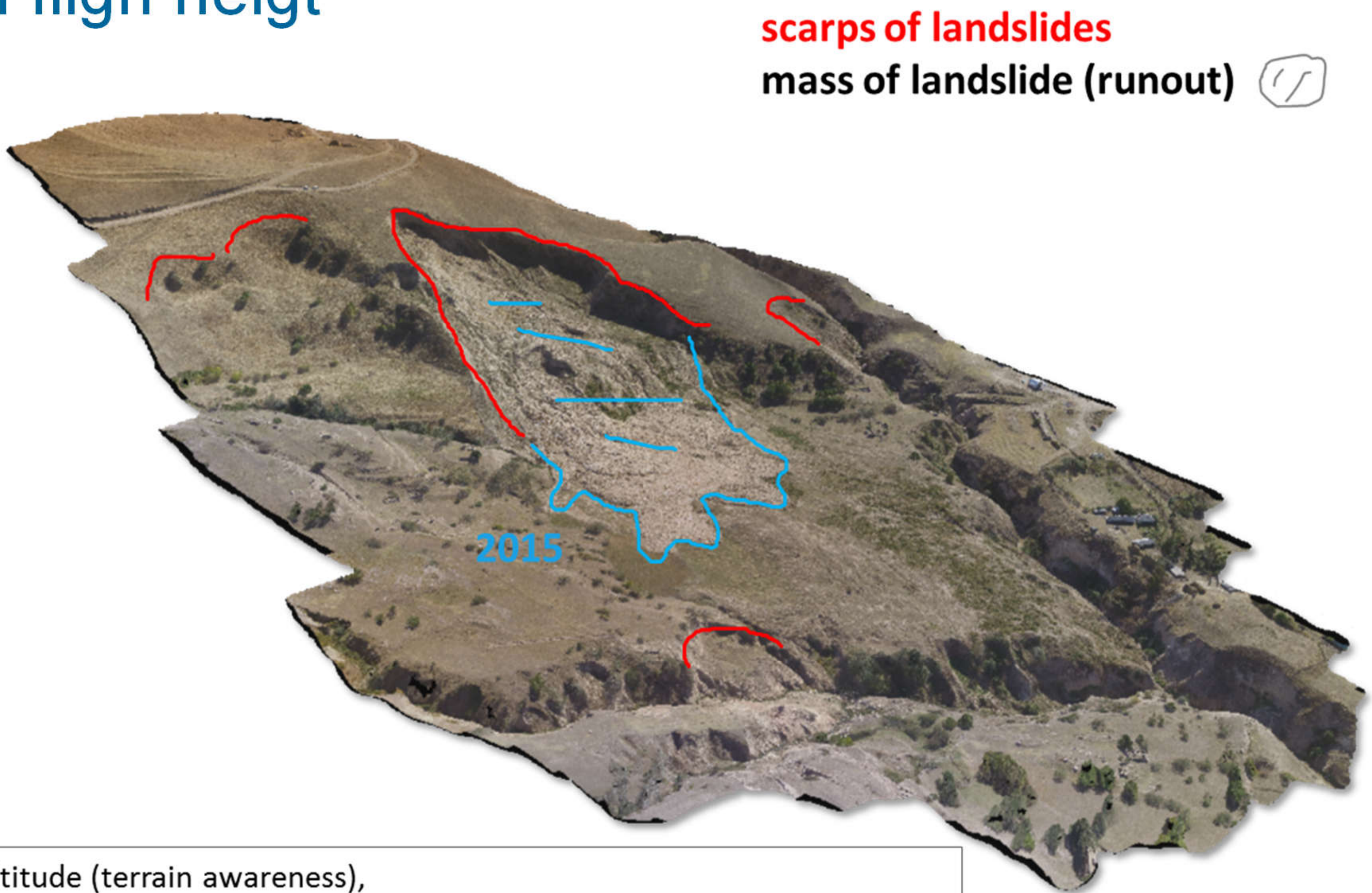
<u>Agisoft Software</u>

- 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

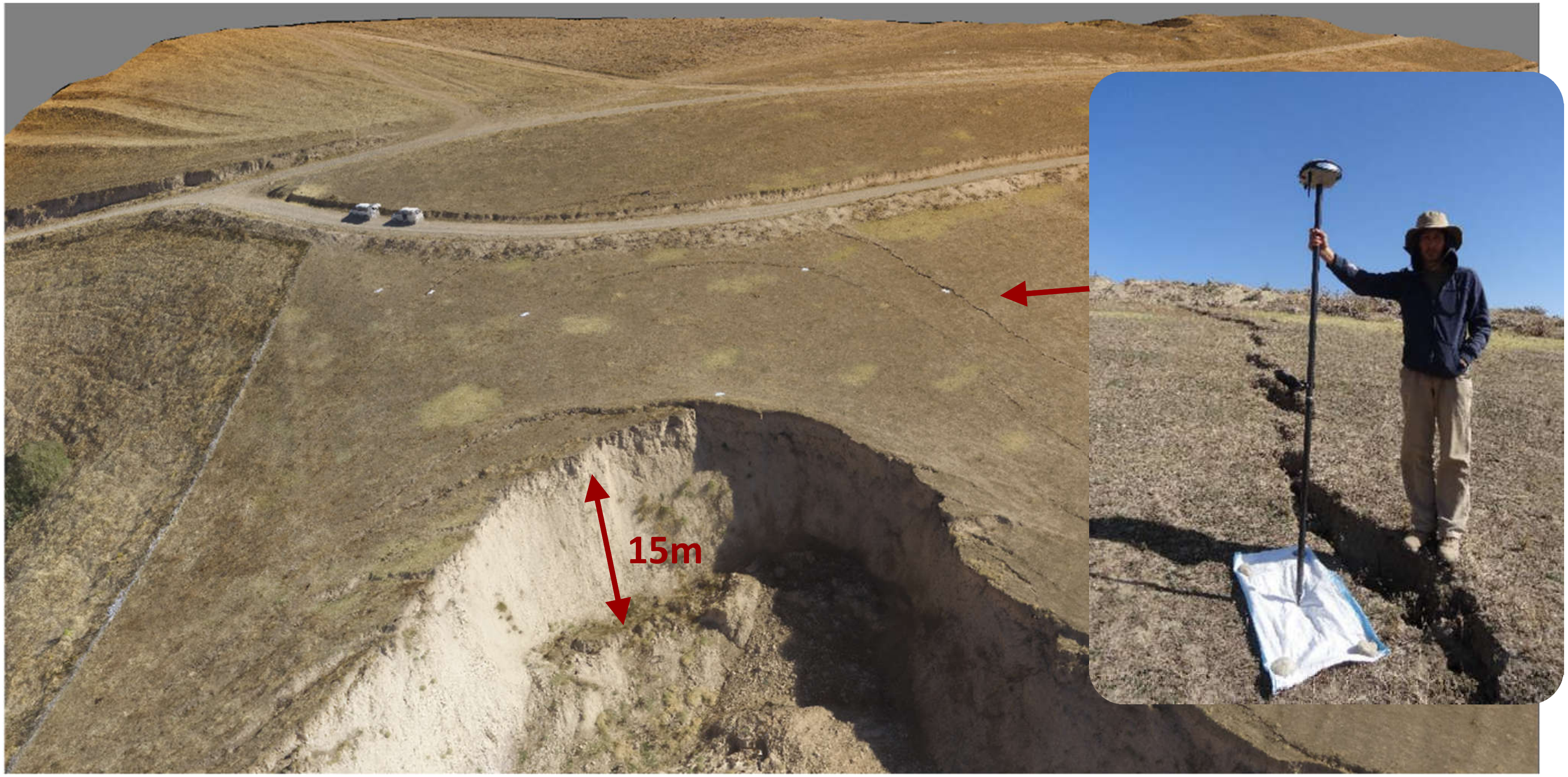
Sogot landslide – DEM overlaid by orthophotos 150m fligh heigt



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

Sogot landslide – 50m flight height for crack survey

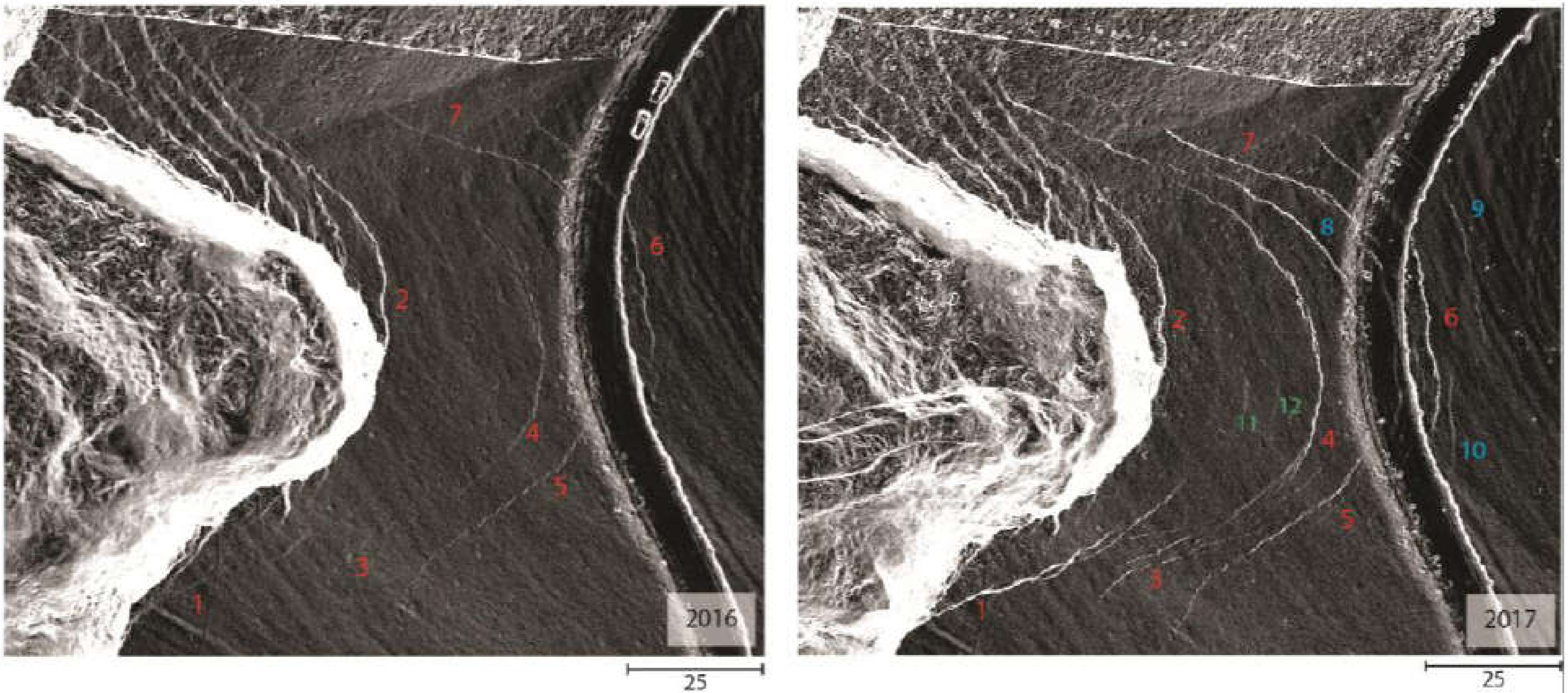
New cracks evolved after 2015 failure, old cracks are reactivated (> 1m depth) – upslope progression of cracks behind main scarp including adjacent road area



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

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

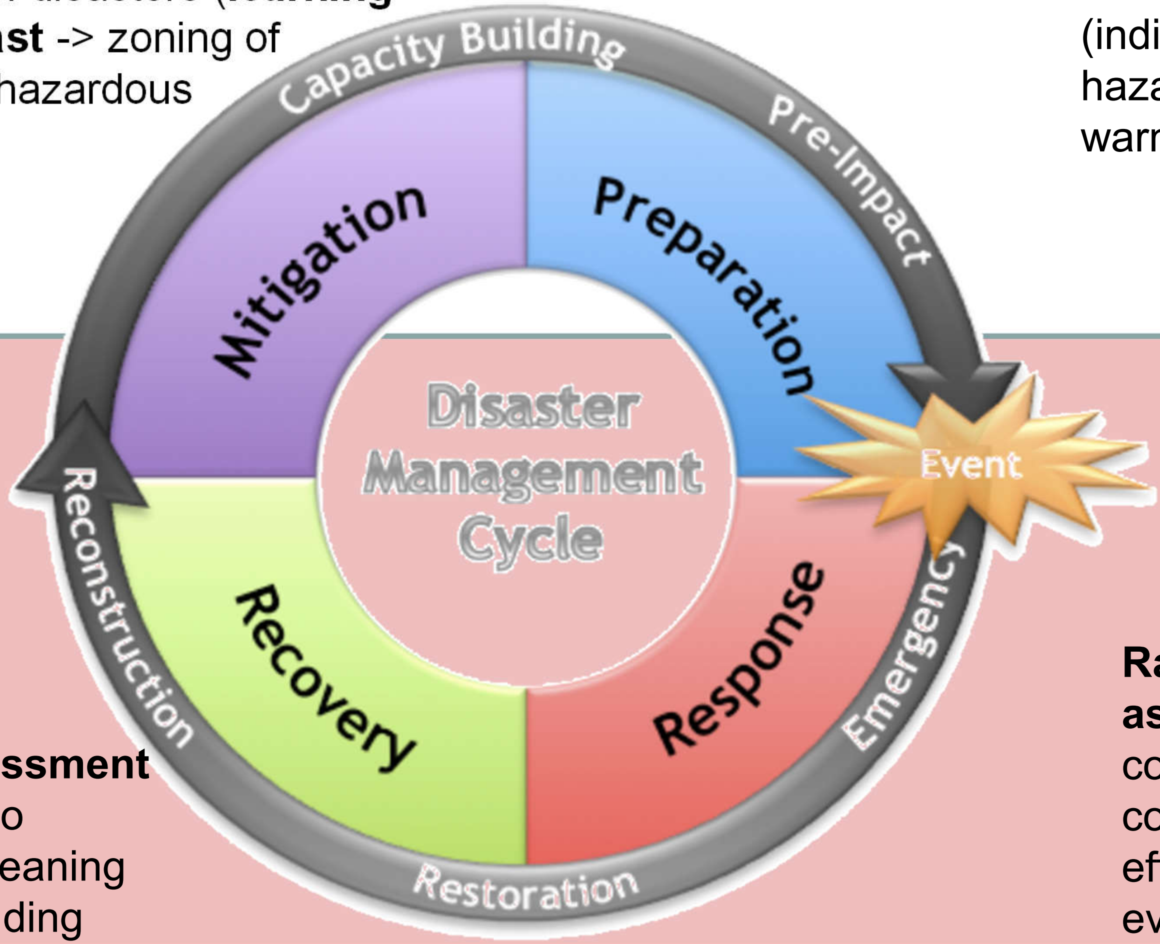


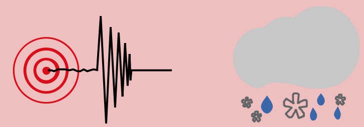
Shaded relief representation of slopes derived from drone-based DEM's for enhancing cracks

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.





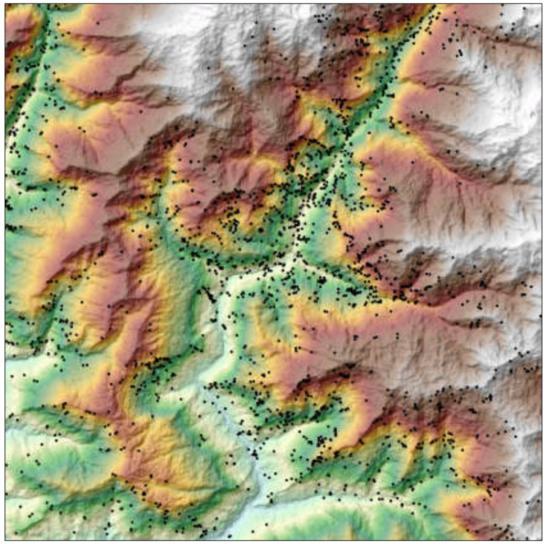
Impact assessment contributing to coordinate cleaning up and rebuilding

Rapid impact assessment contributing to coordinate rescue efforts, first aid, evacuation.

Comparison of co-seismic and monsoon-related landslide occurrence – 7.8 Mw Gorkha Earthquake

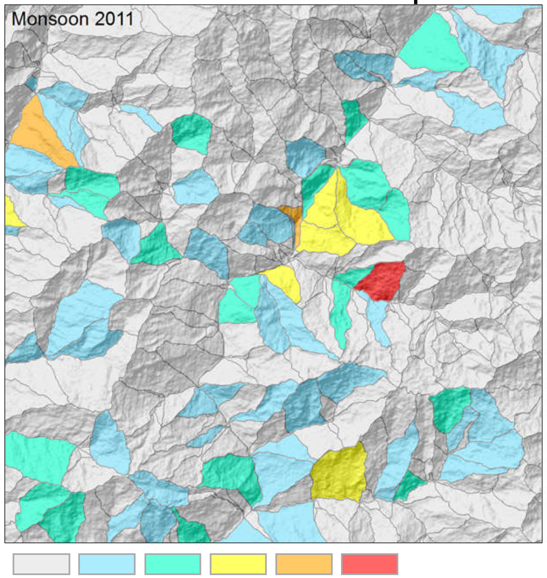
Nepal • Impact of earthquake (25 Apr 2015) • 2011-2016 period • RapidEye

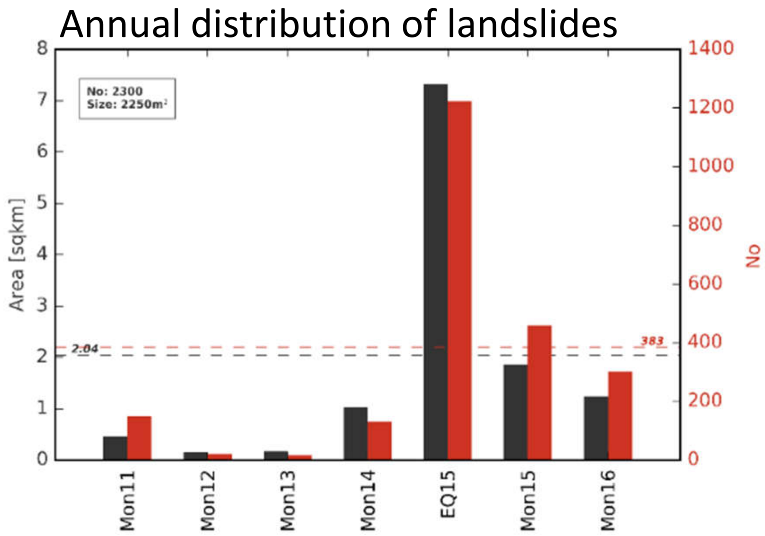
Total detected landslides: 2300



25x25km

Landslides related to slope units





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

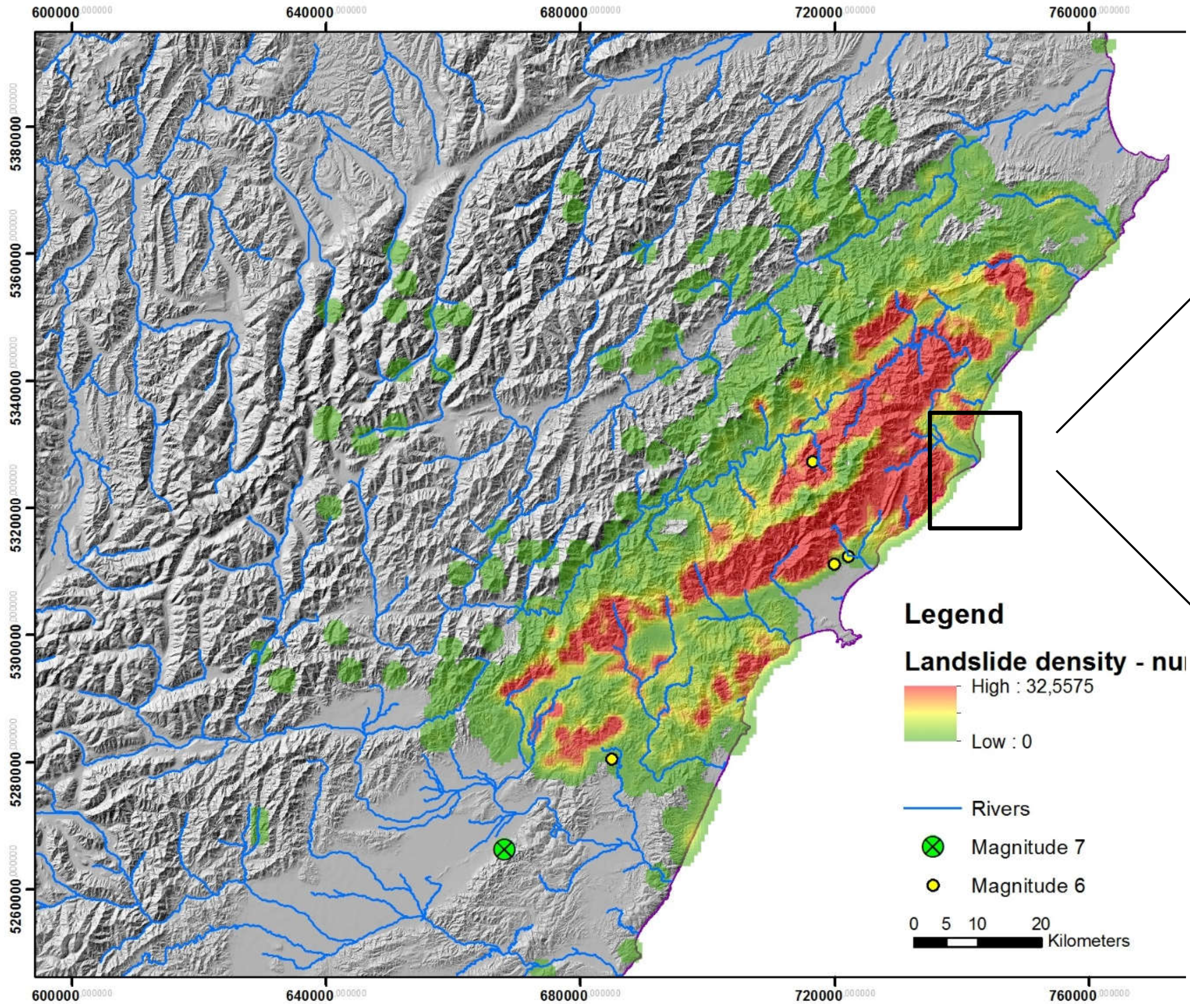
Analysis of impact of earthquake (co-seismic landslide occurrence) on monsoon-related landslide activity including years before and after the 2015 earthquake

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

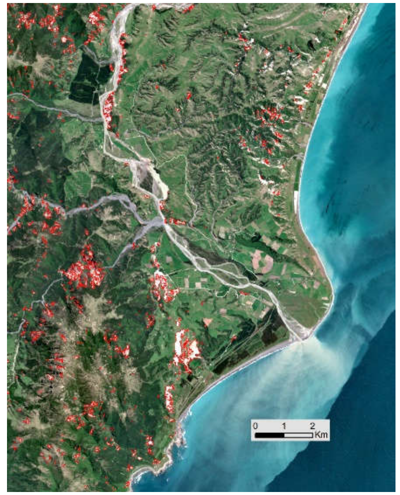
Behling et al. @ WLF4 - 2017

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

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



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

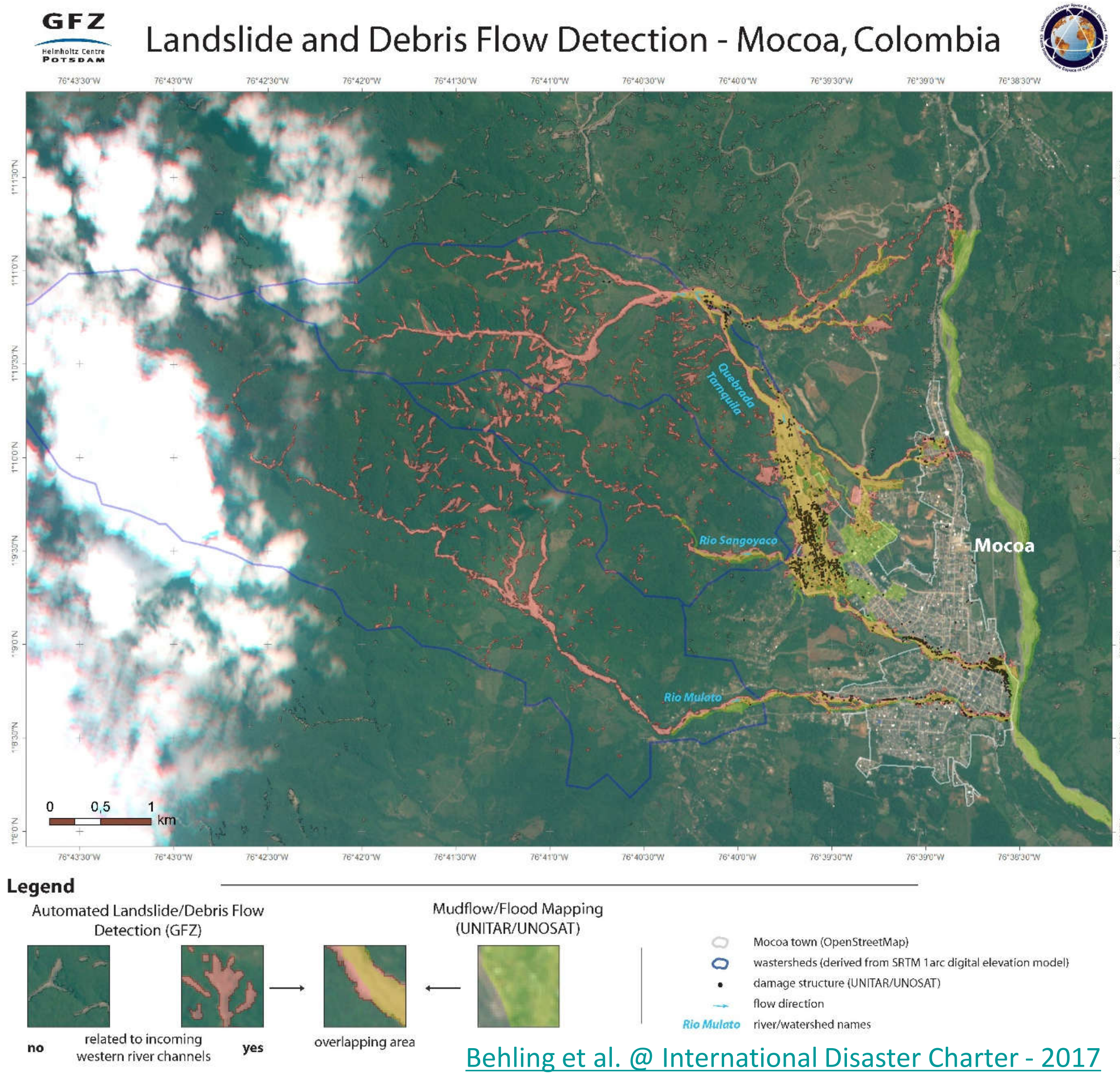


Sentinel 2A - after

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



Behling et al. @ International Disaster Charter - 2017

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

HELMHOLTZ GEMEINSCHAFT

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

Contact

roessner@gfz-potsdam.de, behling@gfz-potsdam.de

References for remote sensing based landslide investigations conducted at GFZ

(1) Automated spatiotemporal landslide mapper

Behling, R., Roessner, S., Segl, K., Kleinschmit, B. & Kaufmann, H., 2014. Robust Automated Image Co-Registration of Optical Multi-Sensor Time Series Data: Database Generation for Multi-Temporal Landslide Detection. *Remote Sensing*, 6, (3), 2572–2600. DOI: 10.3390/rs6032572

Behling, R., Roessner, S., Kleinschmit, B., Kaufmann, H., 2014. Automated Spatiotemporal Landslide Mapping over Large Areas Using RapidEye Time Series Data. *Remote Sensing*, 6, (9), 8026-8055. DOI: 10.3390/rs6098026

Related data pulbication: Behling, Robert; Roessner, Sigrid (2020): Multi-temporal landslide inventory for a study area in Southern Kyrgyzstan derived from RapidEye satellite time series data (2009 – 2013). V. 1.0. GFZ Data Services. http://doi.org/10.5880/GFZ.1.4.2020.001

Behling, R., Roessner, S., Golovko, D., Kleinschmit, B., 2016. Derivation of long-term spatiotemporal landslide activity — A multi-sensor time series approach. *Remote Sensing of Environment* 186, 88–104. DOI: 10.1016/j.rse.2016.07.017

Related data publication: Behling, Robert; Roessner, Sigrid (2020): Multi-temporal landslide inventory for a study area in Southern Kyrgyzstan derived from multi-sensor optical satellite time series data (1986 – 2013). V. 1.0. GFZ Data Services. http://doi.org/10.5880/GFZ.1.4.2020.002

Behling, R., 2016. Derivation of spatiotemporal landslide activity for large areas using long-term multi-sensor satellite time series data. *PhD Thesis*, Berlin, Technical University of Berlin, 169 pp. http://dx.doi.org/10.14279/depositonce-5525

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

Marc, O., Behling, R., Andermann, C., Turowski, J., Illien, L., Roessner, S., Hovius, N. (2019): Long-term erosion of the Nepal Himalayas by bedrock landsliding: the role of monsoons, earthquakes and giant landslides. *Earth Surface Dynamics*, 7, 107-128. https://doi.org/10.5194/esurf-7-107-2019

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

Golovko, D., Roessner, S., Behling, R., Wetzel, H.-U., Kaufmann, H., 2014. GIS-Based Integration of Heterogeneous Data for a Multi-temporal Landslide Inventory. In: K. Sassa, P. Canuti, & Y. Yin, eds. *Landslide Science for a Safer Geoenvironment*, Volume 2: Methods of Landslide Studies. Cham: Springer International Publishing, 799 – 804, doi: 10.1007/978-3-319-05050-8

Golovko, D., Roessner, S., Behling, R., Wetzel, H.-U., Kleinschmidt, B., 2015. Development of Multi-Temporal Landslide Inventory Information System for Southern Kyrgyzstan Using GIS and Satellite Remote Sensing. *PFG*, 2, 157-172, doi: http://doi.org/10.1127/pfg/2015/0261

Golovko, D., Roessner, S., Behling, R., Kleinschmit, B., 2017. Automated derivation and spatio-temporal analysis of landslide properties in Southern Kyrgyzstan. *Natural Hazards*, 1-28. doi:10.1007/s11069-016-2636-y.

Golovko, D., Roessner, S., Behling, R., Wetzel, H.-U., Kleinschmit, B., 2017. Evaluation of Remote-Sensing-Based Landslide Inventories for Hazard Assessment in Southern Kyrgyzstan. *Remote Sensing*, 9(9), 943, doi:10.3390/rs9090943

Golovko, D., 2019. Spatio-temporal analysis of landslide hazard in Southern Kyrgyzstan using GIS and Remote Sensing data, *PhD Thesis*, Berlin, Technichal University, 124 pp. http://dx.doi.org/10.14279/depositonce-8504

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

Motagh, M., H.-U. Wetzel, S. Roessner, Kaufmann, 2013. A TerraSAR-X InSAR study of landslides in southern Kyrgyzstan, Central Asia. *Remote Sensing Letters*, 4, (7), 657–666. doi:10.1080/2150704X.2013.782111.

Teshebaeva, K., Roessner, S., Echtler, H., Motagh, M., Wetzel, H.-U., Molodbekov, B., 2015. ALOS/PALSAR InSAR Time-Series Analysis for Detecting Very Slow-Moving Landslides in Southern Kyrgyzstan. *Remote Sensing*, 7, (7), 8973-8994, doi: 10.3390/rs70708973

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/9674

Teshebaeva, K. Echtler, H., Bookhagen, B., Strecker, M., 2019. Deep-seated gravitational slope deformation (DSGSD) 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