Multi-temporal remote sensing and GIS-based analysis for landslide detection

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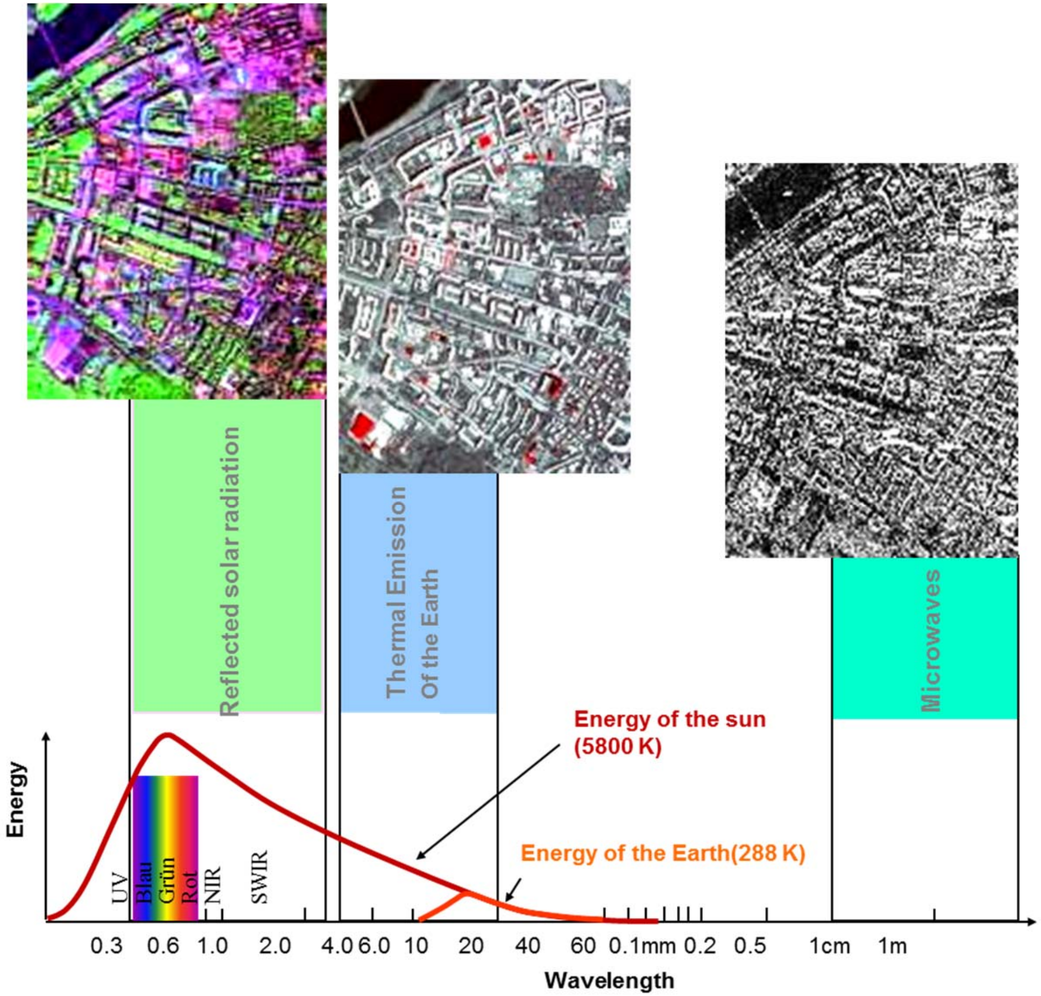
Main research topics of GFZ Remote Sensing Section



Use of multi-sensor data across different parts of electromagnetic spectrum

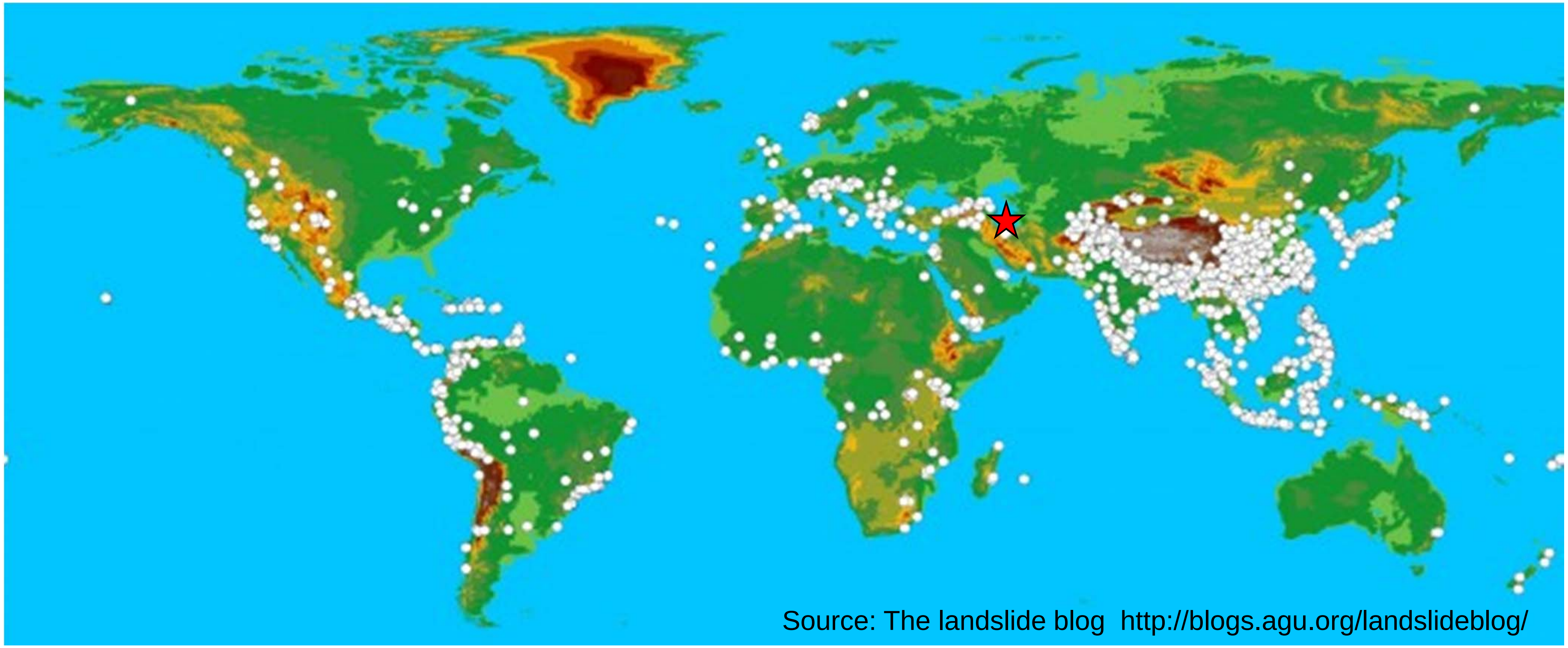
Methodological developments:

- **Imaging spectroscopy**
  - Sensor development (EnMap)
  - Calibration / validation
  - Material identification
  - Object recognition
  - Change detection
- **InSAR- Interferometry**
  - Deformation modelling
  - Time series analysis

Applications:

- **Natural hazards**
- Soil / vegetation studies
- Dry land degradation
- Mineral exploration
- Mine waste Analysis
- Urban development

Global occurrence of fatal landslides during period 2002-2012

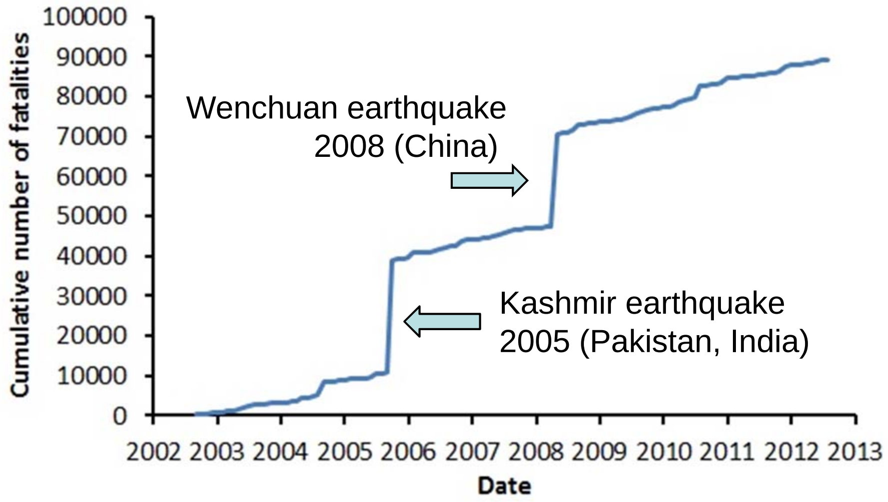


Global hotspots:

- Central to SE Asia: (China, India, Sri Lanka, southern edge of Himalayan Arc)
- Indonesia, Phillipines
- Central Carabian Islands
- Mountain chains along the western coast of the Americas

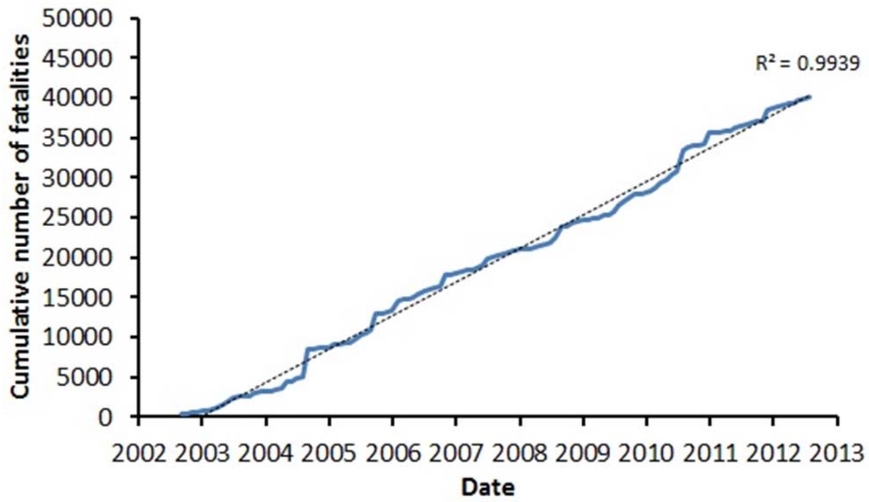
World-wide reported landslide fatalities during period 2002-2012

Total:



- 89,177 fatalities
- ca. 9000 fatalities per year

Without earthquake induced landslides:



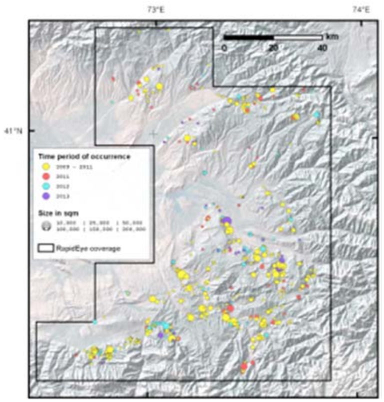
- 40,123 non-seismically induced landslide fatalities
- Linear trend

Source: The landslide blog http://blogs.agu.org/landslideblog/

Why remote sensing based landslide analysis is needed

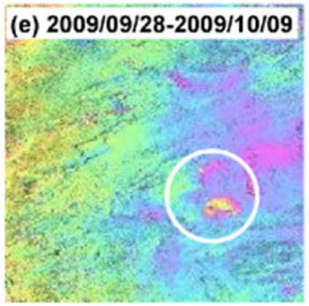
- Process knowledge is limited for many parts of the world – **understanding of past** landslide occurrence is **key for prediction of future** landslide activity
- **Need for systematic longterm assessment** of landslide activity in form of regular multi-temporal landslide inventories
- Due to **large size and limited accessibility of many affected areas** satellite remote sensing data of suitable spatial and temporal resolution often represent only existing area-wide archive of landslide-related surface changes
- Satellite remote sensing allows assessment of **backdated landslide activity** as well as **monitoring of ongoing landslide activation**
- **Combination of optical and radar remote sensing** enables more complete process analysis in time and space
- Satellite remote sensing can be used for **spatial extrapolation of ground-based observations** in the frame of multi-scale process analysis
- Resulting **improved spatio-temporal process understanding** can be incorporated into various **hazard and risk assessment practices**

Potential contributions of multi-temporal remote sensing



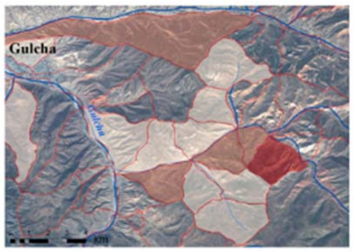
Optical Satellite Remote Sensing

- Automated identification of landslide failures at regional scale
- Systematic analysis of backdated landslide activity using archived data
- Regular monitoring to assess ongoing landslide activity



Radar Satellite Remote Sensing

- Identification of ongoing deformation within active landslide prone slopes
- Monitoring of slope activation -> potential precursors for early warning
- Combined analysis of optical and radar data for improved temporal resolution



GIS-based Hazard Assessment

- Development of dynamic landslide inventory systems by combining results from remote sensing analysis with data from all available sources
- Derivation of improved spatiotemporal process understanding
- Generation of input information for dynamic hazard and risk assessment

Overall approach for automated multi-temporal landslide detection

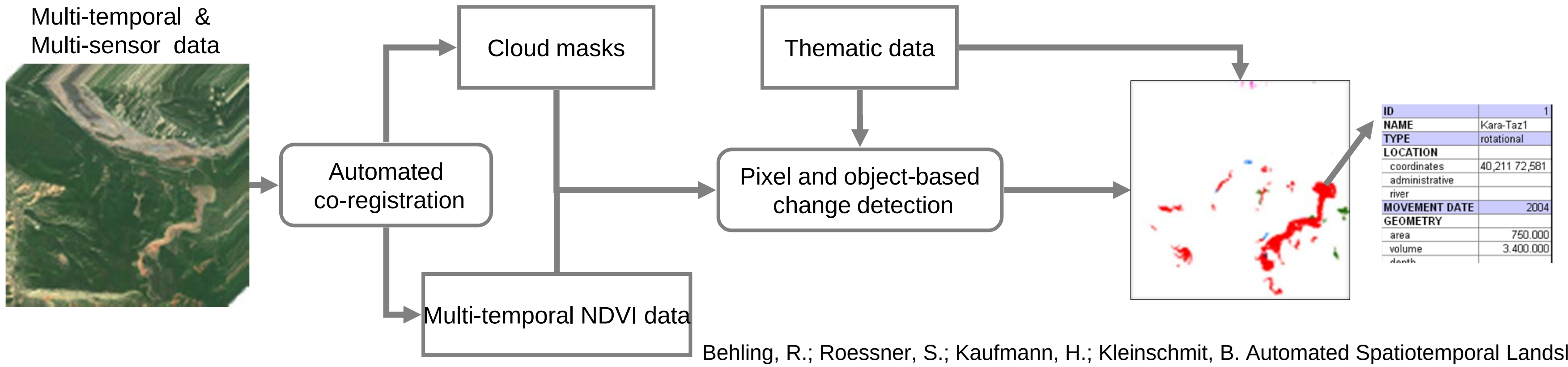
<u>Challenges</u>

- High seasonal and long-term surface variability
- Large area of ~12 000 km²
- High amount of multi-sensor satellite data
- Automated, efficient and robust techniques needed for multi-sensor time-series-analysis

<u>Pre-processing</u>

<u>Derivation of landslide objects</u>
-> bi- & multi-temporal change detection
-> Segmentation

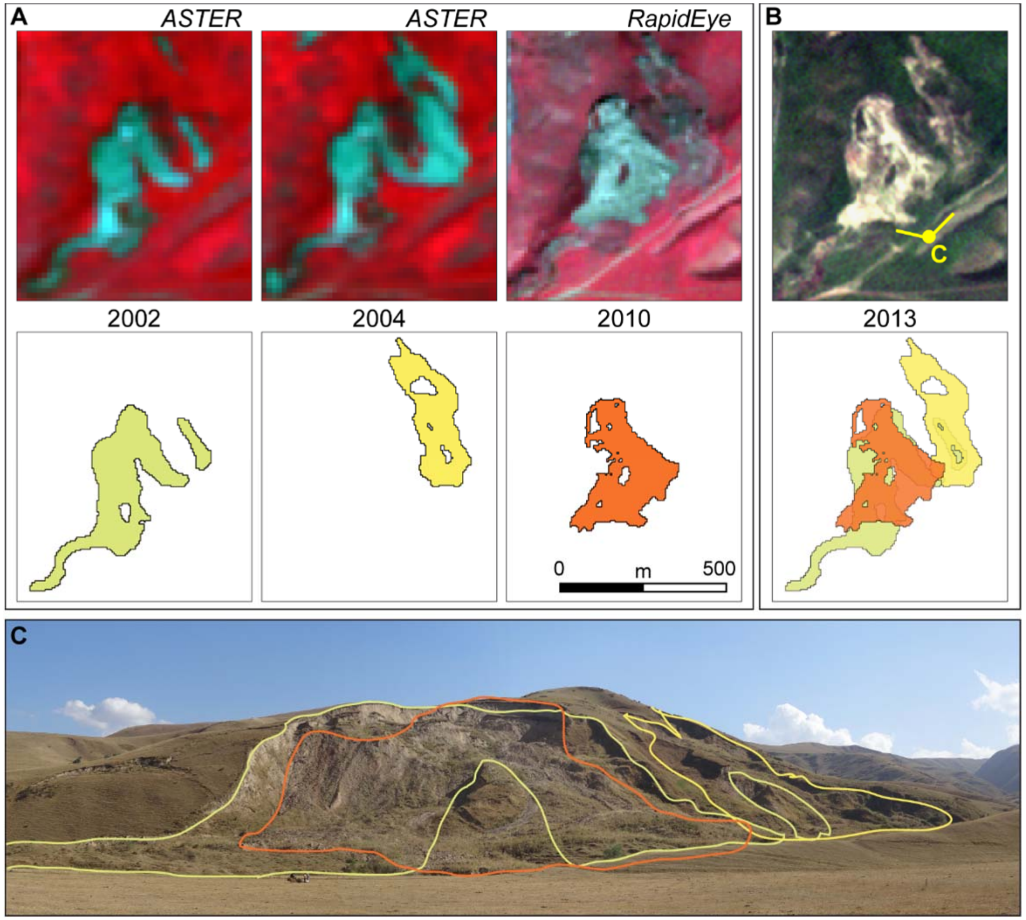
<u>Spatio-temporal landslide inventoy</u>
-> Quantitative and qualitative
characterization of landslide objects



Behling, R.; Roessner, S.; Kaufmann, H.; Kleinschmit, B. Automated Spatiotemporal Landslide Mapping over Large Areas Using RapidEye Time Series Data. *Remote Sensing*, 2014, 9, 8026-8055.

Behling, R.; Roessner, S.; Segl, K.; Kleinschmit, B.; Kaufmann, H. Robust Automated Image Co-Registration of Optical Multi-Sensor Time Series Data: Database Generation for Multi-Temporal Landslide Detection. *Remote Sensing*, 2014, 6, 2572-2600.

Result: object-based multi-temporal landslide identification



Behling, R.; Roessner, S.; Golovko, D.; Kleinschmit, B.. Derivation of long-term spatiotemporal landslide activity – An automated multi-sensor time series approach.
Under review Remote Sensing of Environment

Identification of landslide objects and their time period of occurrence

Detection of landslide failures of different shapes, sizes, types, lithology, morphology

Landslide detection based on irregular time-series acquired by different sensors

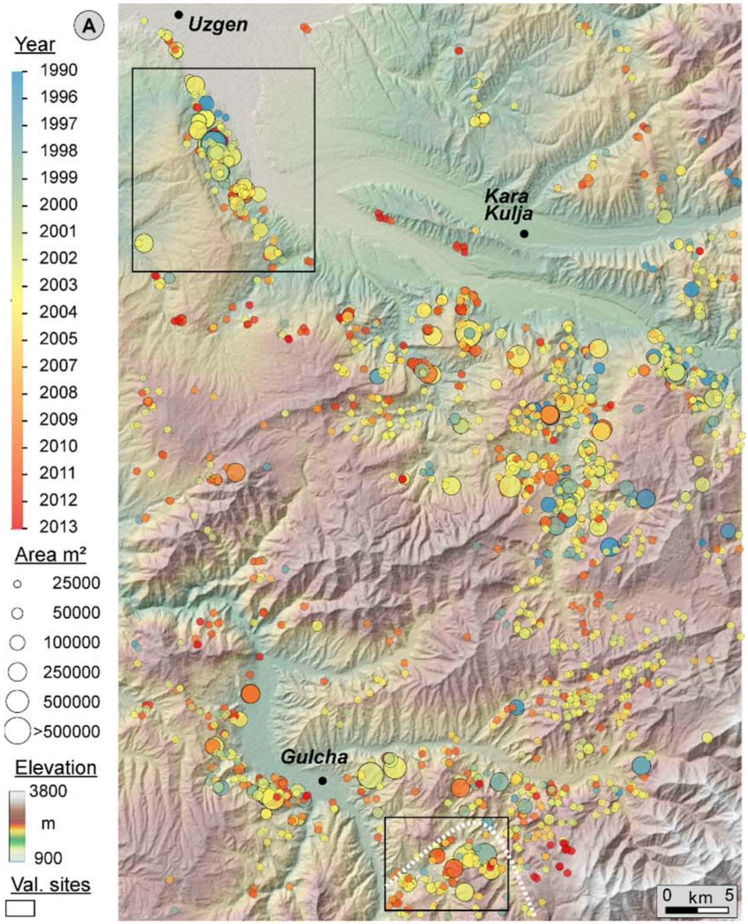
Enables systematic analysis of spatiotemporal landslide occurrence at regional scale

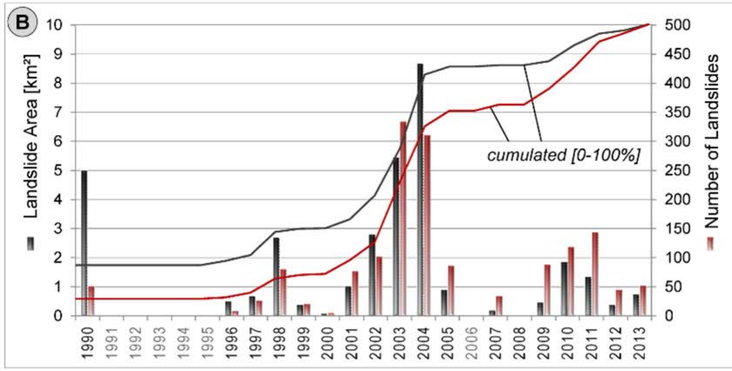
Provides input information required for objective landslide hazard and risk assessment

Challenges:
Limited temporal resolution due to cloud coverage and irregular data acquisitions

New opportunities:
Combined analysis of optical and radar data with high temporal resolution using Sentinel-1/2 data covering large areas (swath width 250 – 290 km)

Multi-sensor analysis of long-term landslide activity





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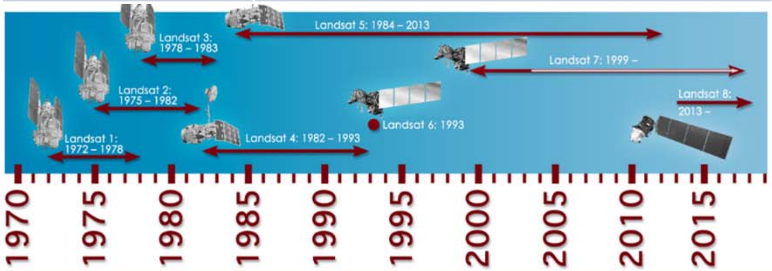
Year	No*	Area of Landslide Objects (m²) Total*	Min	Max	Mean
1990	51 (0.9)	5006820 (4.1)	2575	2881511	509001
1996	8 (0.1)	505184 (0.4)	2775	223825	71183
1997	26 (0.4)	666129 (0.5)	1950	114100	25127
1998	80 (1.4)	2701243 (2.2)	2300	381500	37878
1999	20 (0.3)	373754 (0.3)	3400	85700	19384
2000	5 (0.1)	81675 (0.1)	5125	32525	16335
2001	77 (1.3)	1016404 (0.8)	1775	90475	14682
2002	102 (1.7)	2802906 (2.3)	2425	539825	38692
2003	334 (5.7)	5446990 (4.4)	1450	349925	34407
2004	311 (5.3)	8676912 (7.1)	1000	1258388	40679
2005	86 (1.5)	903473 (0.7)	950	108948	15473
2007	34 (0.6)	177275 (0.1)	900	26850	7726
2008	1 (0.0)	1950 (0.0)	1950	1950	1950
2009	88 (1.5)	461685 (0.4)	150	105209	5844
2010	119 (2.0)	1856543 (1.5)	175	184475	16822
2011	144 (2.5)	1353248 (1.1)	50	129400	9888
2012	45 (0.8)	384498 (0.3)	450	53025	8544
2013	52 (0.9)	746541 (0.6)	250	484730	20609
All	1583	33163230	50	2881511	20950

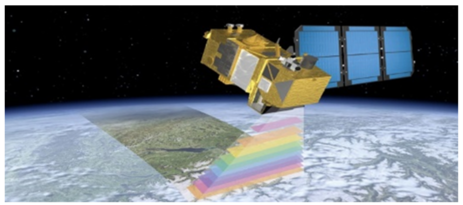
*number in brackets: relation to long-term annual average rate (No: 57, Area: 1.2km²)

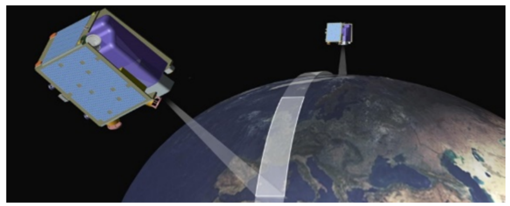
Behling, R.; Roessner, S.; Golovko, D.; Kleinschmit, B.. Derivation of long-term spatiotemporal landslide activity – An automated multi-sensor time series approach. Under review Remote Sensing of Environment

Continuation of monitoring with high resolution time series data

	Landsat-8	RapidEye	Sentinel-2
Spectral Resolution	OLI ms bands 1-7,9: OLI pan band 8: TIRS bands 10-11:	R / G / B / RedEdge / NIR 55 – 90 nm	RGB/NIR: 30 – 115 nm RedEdge/SWIR: 15 – 180 nm Atm.- corr. bands: 20 – 30 nm
Spatial Resolution	OLI ms bands 1-7,9: 30 m OLI pan band 8: 15 m TIRS bands 10-11: 100 m	6,5 m	RGB/NIR: 10 m RedEdge/SWIR: 20 m Atm.- correction bands: 60 m
Swath	185 km (Tiles of 30 x 30km)	77 km (Tiles of 25 x 25km)	290 km
Repetition Rate	16 days	1 day / 5 sats	10 days / 1 sat.; 5 days / 2 sats.
Launch	2013 (design life of 5 years, fuel for 10 years)	2008	S-2A - 06/2015, S-2B - 07/2016
Data Access	http://earthexplorer.usgs.gov/ (free of charge)	http://eyefind.rapideye.com/ 1$/km² / free for scientific use	https://scihub.esa.int/ (free of charge)
Available data level	at sensor radiance/geocoded	at sensor radiance/geocoded	in commissioning phase

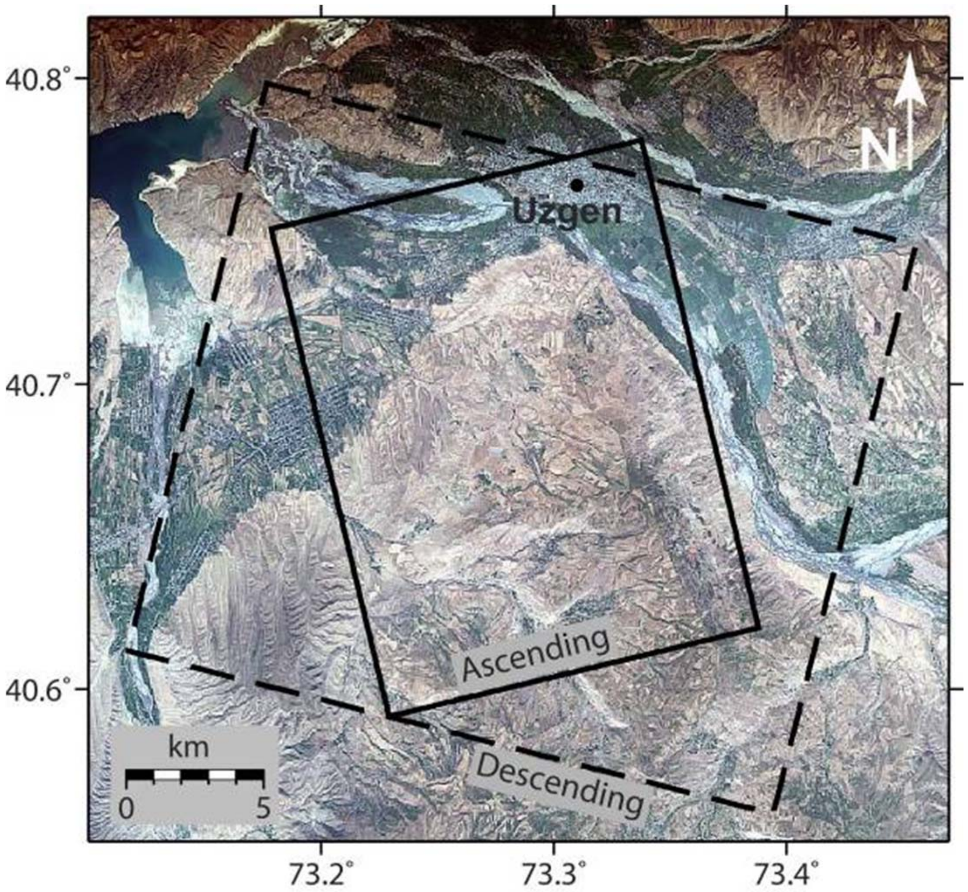






(image source: www.blackbridge.com, www.esa.org)

Ground deformation analysis using radar data (InSAR)



Data: May-October 2009

Radar (active microwave)

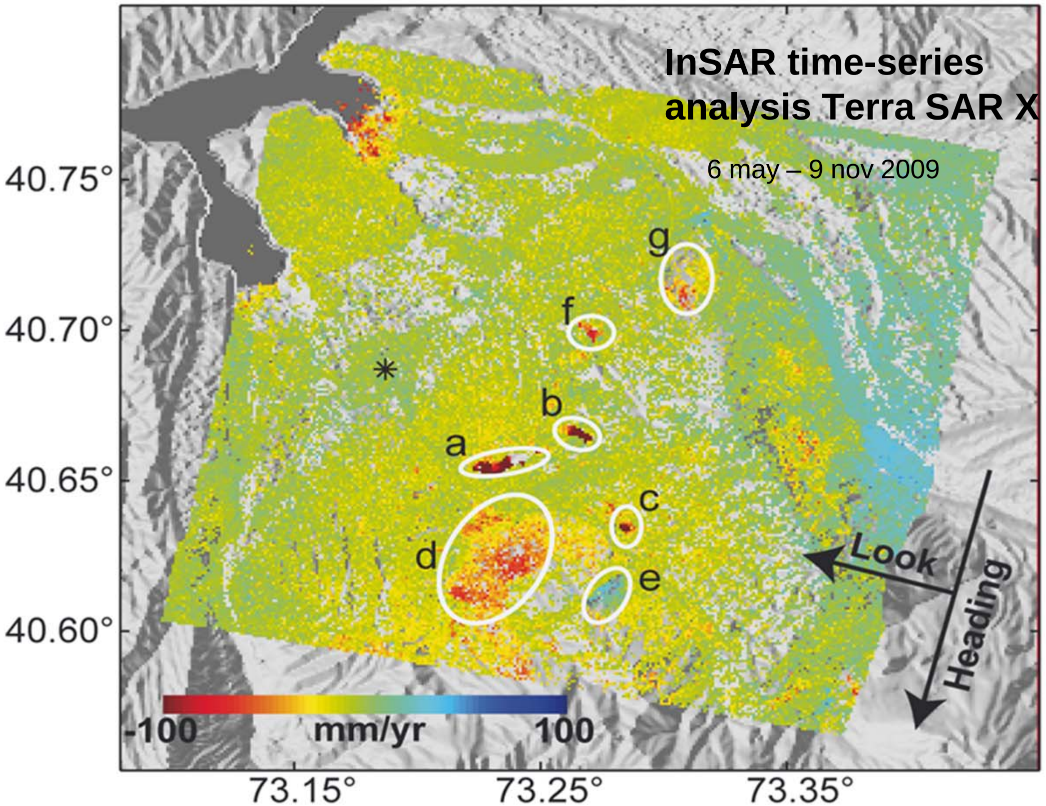
- Independent of weather conditions (clouds)
- X-band (Terra-SAR-X)
- L-Band ALOS-PALSAR)

InSAR:

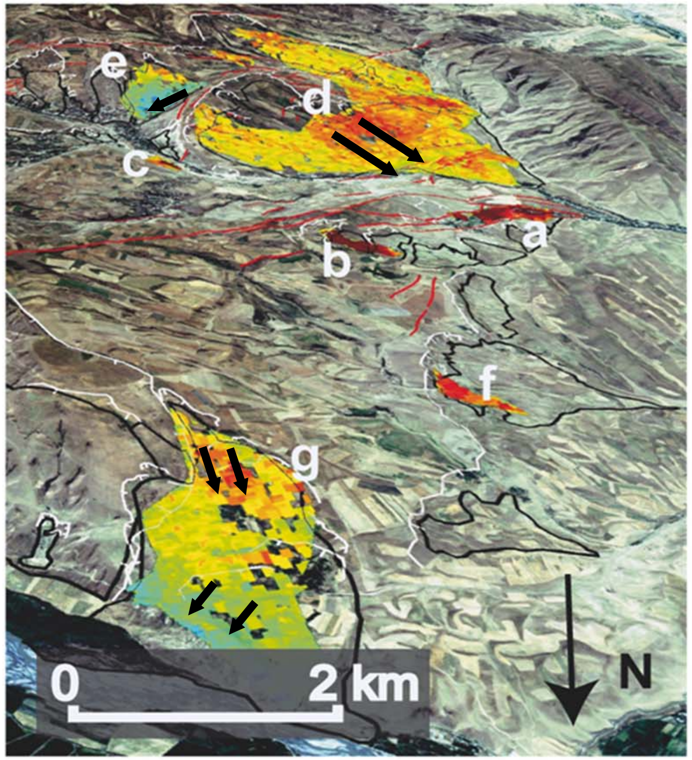
- Phase differences between two SAR images
- Detection of ground deformation (mm-range relative to sensor: parrallel to line of sight)
- **Identification of landslide activation prior to main failures – precursors**
- Not suitable for sudden large failures

Radar Interferometry (InSAR) time series analysis of slope deformation as precursors for larger failures

(A) TSX velocity map

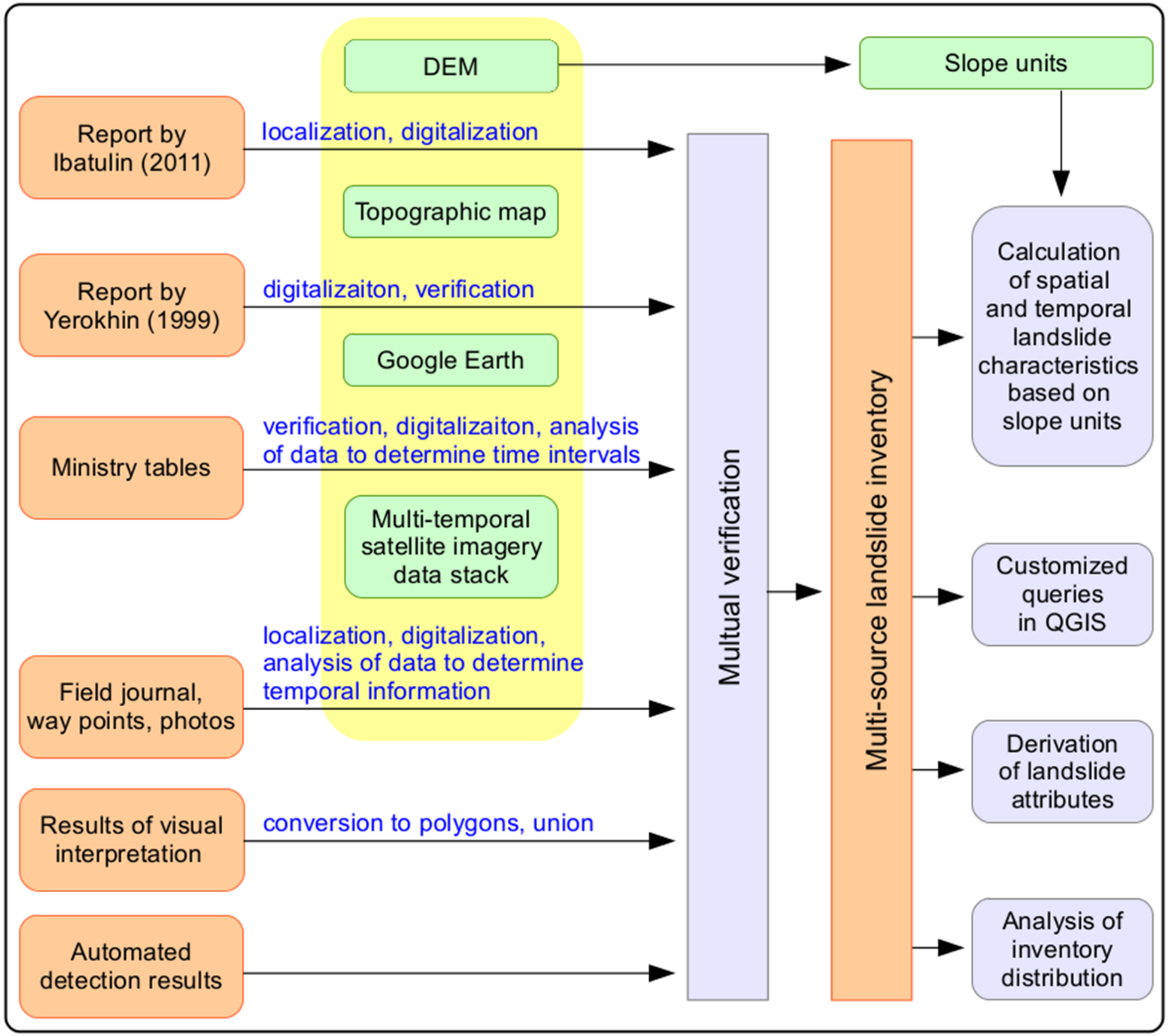


(B) RapidEye imagery



Motagh, M., Wetzel, H.-U., Roessner, S., Kaufmann, H. *Remote Sensing Letters*, 2014, 4, 7, 657- 666.

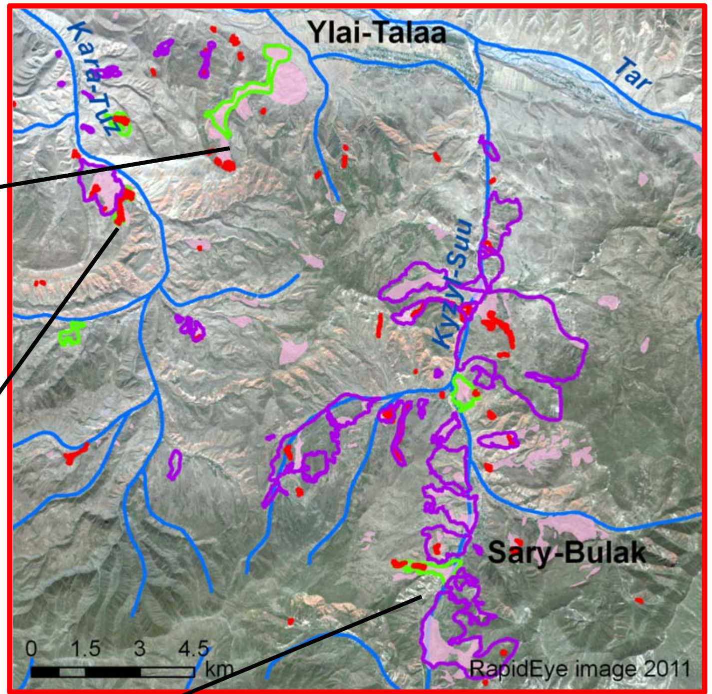
Workflow for GIS-based multi-source landslide inventory and analysis system



Golovko, D., Roessner, S., Behling, R., Wetzel, H.-U., Kleinschmit, B. Development of Multi-Temporal Landslide Inventory Information System for Southern Kyrgyzstan Using GIS and Satellite Remote Sensing. – Photogrammetrie – Fernerkundung – Geoinformation – PFG, 2015, 2, 157-172.

Exemplary information contained in multi-source landslide inventory system

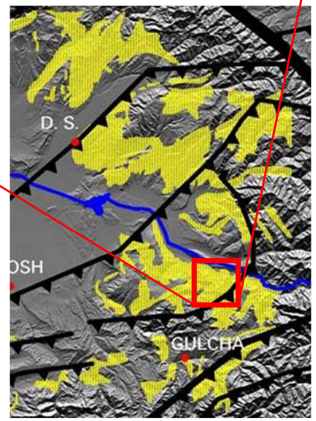
Known failures:
30.03.1982,
April 2004



Known failures:
25.03.2005

Known failures:
27.05.1993,
26.06.1998
09.05.2004

- Data of Kyrgyz authorities
- Field mapping
- Visual interpretation
- Automated detection



Conclusions and outlook

- The use of **multi-temporal remote sensing** and **GIS based data integration** enables higher level of landslide inventory completeness.
- Resulting **multi-temporal landslide inventories** allow improved spatiotemporal characterization of landslide occurrence and represent important **input information for hazard and risk analysis.**
- Analysis of large areas requires development of **automated methods for multi-temporal landslide identification** and subsequent hazard and risk analysis.
- Presented methodological experience has been mainly gained from **large-area analysis of landslide occurrence in Southern Kyrgyzstan** (Central Asia).
- **Future work** will focus on adaptation of developed methods for longer-term analysis of large-area **landslide occurrence related to 2015 Nepal earthquake.**
- **Future goal** of developing a **global landslide mapper** for systematic large-area analysis of landslide occurence based on multi-sensor data (focus Sentinel-1/2).
- **Future contribution** of methodological expertise **to CEOS landslide pilot.**