URBAN LANDSLIDES
risks, disasters and mitigation

Mihai NICULIȚĂ

Associate Professor in Geomorphology and Physical Geography

Departament of Geography, Faculty of Geography and Geology,

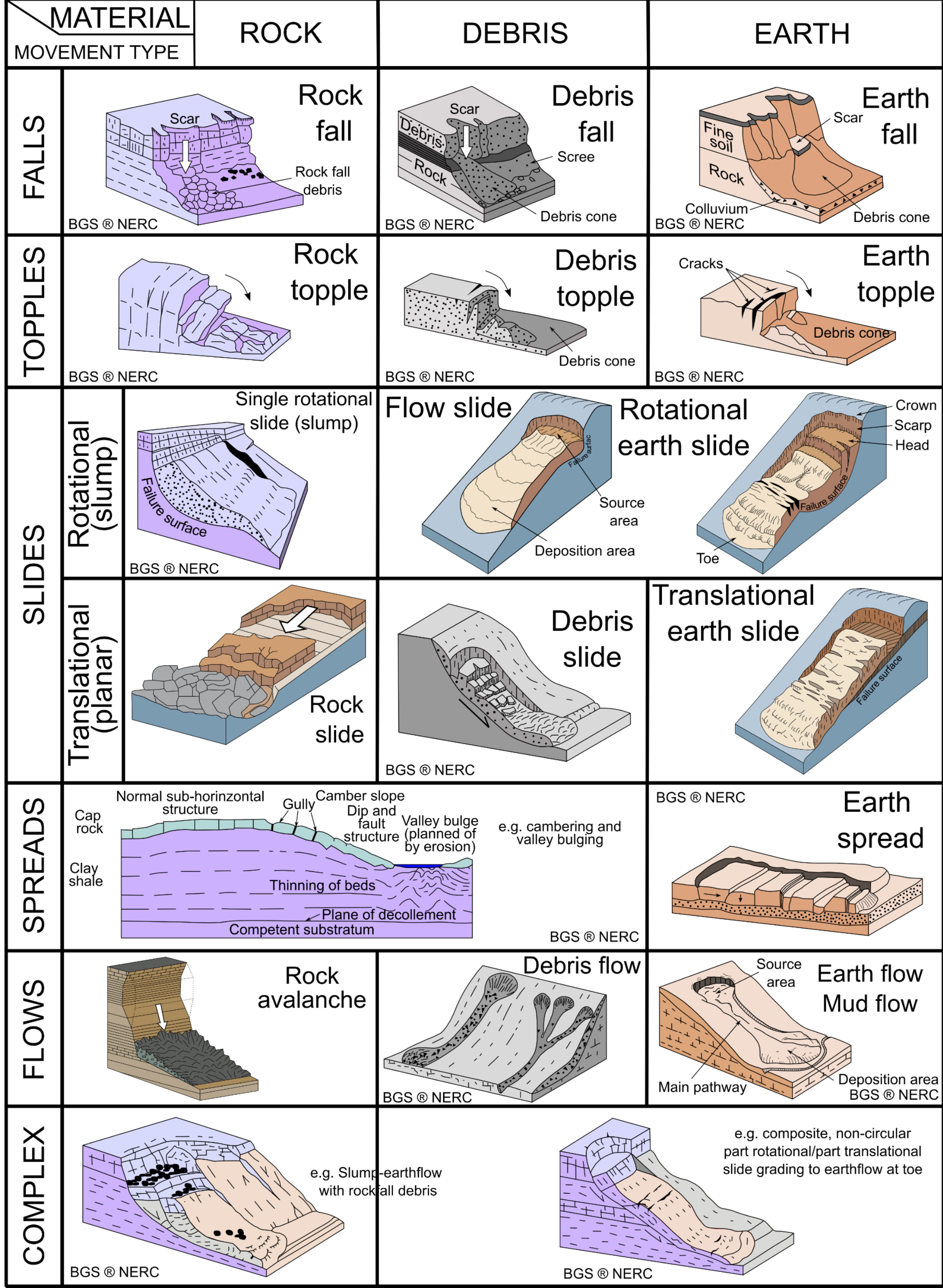
Alexandru Ioan Cuza University of Iași, mihai.niculita@uaic.ro

Introduction

- Plainly speaking urban landslides are landslides that happen in urban areas.
- The definition of urban might vary from place to place, but the emphasis is put on the high density of population and infrastructure, that will induce big material and life losses, compared with landslides produced elsewhere.
- Landslides are movements of mass of rock, earth, or debris down a slope (Cruden, 1991). Sudden triggering and high speed are other characteristics that characterize the phenomenon (while slow movement is also characteristic, we should not compare it with creep which is a steady particle-by-particle long-term movement).

- Landslides happen in many urban areas, in developed or developing countries, from temperate to tropical zones, both in mountainous, hilly, or coastal environments (Alexander, 1989). Flat areas are not exempted, especially in earthquake-prone areas (through liquefaction), while submarine landslides can trigger tsunamis that affect flat coastal areas.
- Volcanic areas are also prone to catastrophic landslides triggered by volcanic activity (land or submarine), and recently wildfires leave the soil unprotected against rainfall that can trigger debris and mudflows.
- Besides life loss, also through infrastructure damage, landslides do not have to be big. Small but frequent landslides can create material damage that can cripple certain activities or societies.

- Characteristics of landslides make them more/less prone to inflict a certain degree of infrastructure damage or life loss (vulnerability of element at risk). The main classification of landslides is based on mechanism and material (Cruden & Varnes, 1996; Hungr et al., 2014).
- Landslides where water is mixed with the flowing material have the biggest speed and the most potential to cause life loss, due to high mobility.
- Rockfalls have also high speed, but lower mobility; they can also inflict a large number of casualties when have a big magnitude.
- Slides have variable speed (from very slow to quick) and usually destroy infrastructure.

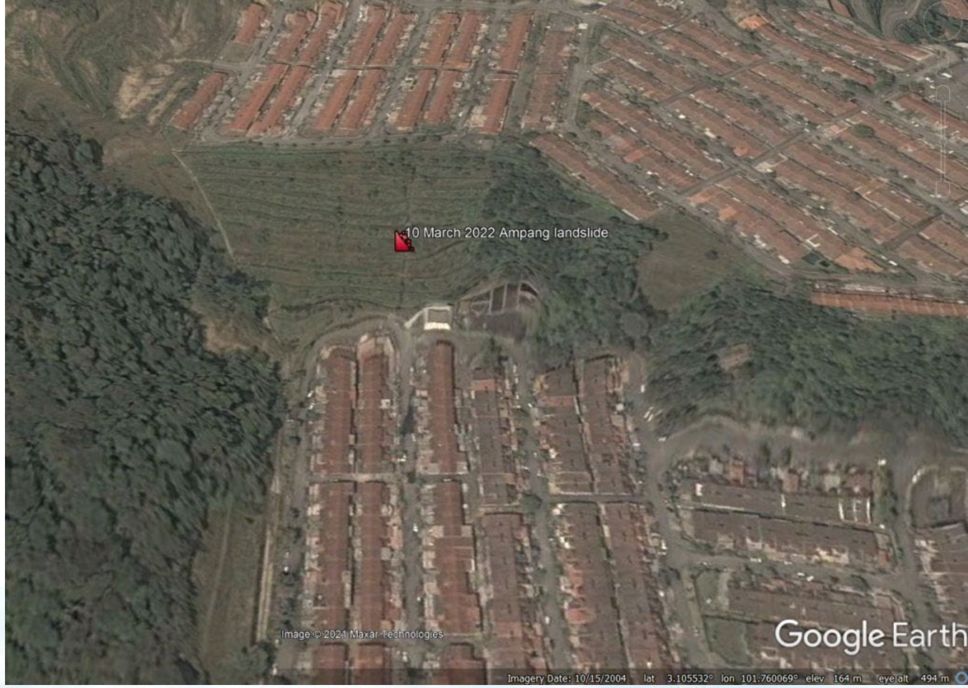


Some examples...

Ampang, Malaysia 10 March 2022

https://blogs.agu.org/landslideblog/2022/03/14/ampang-1/

4 deaths, 1 injured



Petrópolis, Brasil, 17 February 2022

231 deaths

https://www.reuters.com/business/environment/death-toll-brazils-petropolis-rises-104-after-heavy-rains-2022-02-17/

https://blogs.agu.org/landslideblog/2022/02/18/planet-satellite-image-of-the-urban-landslides-in-the-alto-da-serra-area-of-petropolis-brazil/

La Conchita landslide, Ventura, California 4 March 1995, 10 January 2005

9 Houses destroyed

9 people dead

The site has old landslides (1865 the first historical record; the 1909 slide burying the rail line and a train), the 1995 event being triggered by ~ 800 mm of rain.

The 2005 reactivations were triggered by ~ 400 mm of rain.

The avocado farm from above the hillslope was found to be liable after the 2005 event.

https://pubs.usgs.gov/of/2005/1067/508of05-1067.html


2005
https://www.photopilot.com/media/images/blog-la-conchita-2015-3X7A0296.cee84390.fill-1370x800.jpg


2015
https://www.photopilot.com/media/images/blog-la-conchita-2015-3X7A0296.cee84390.fill-1370x800.jpg

Bluebird Canyon Landslide
2 October 1978; 1 June 2005

50 houses

18 “multi-million” houses

A block side triggered along a faultline in sandstones.

2005 event triggered by winter rainfall accumulation.

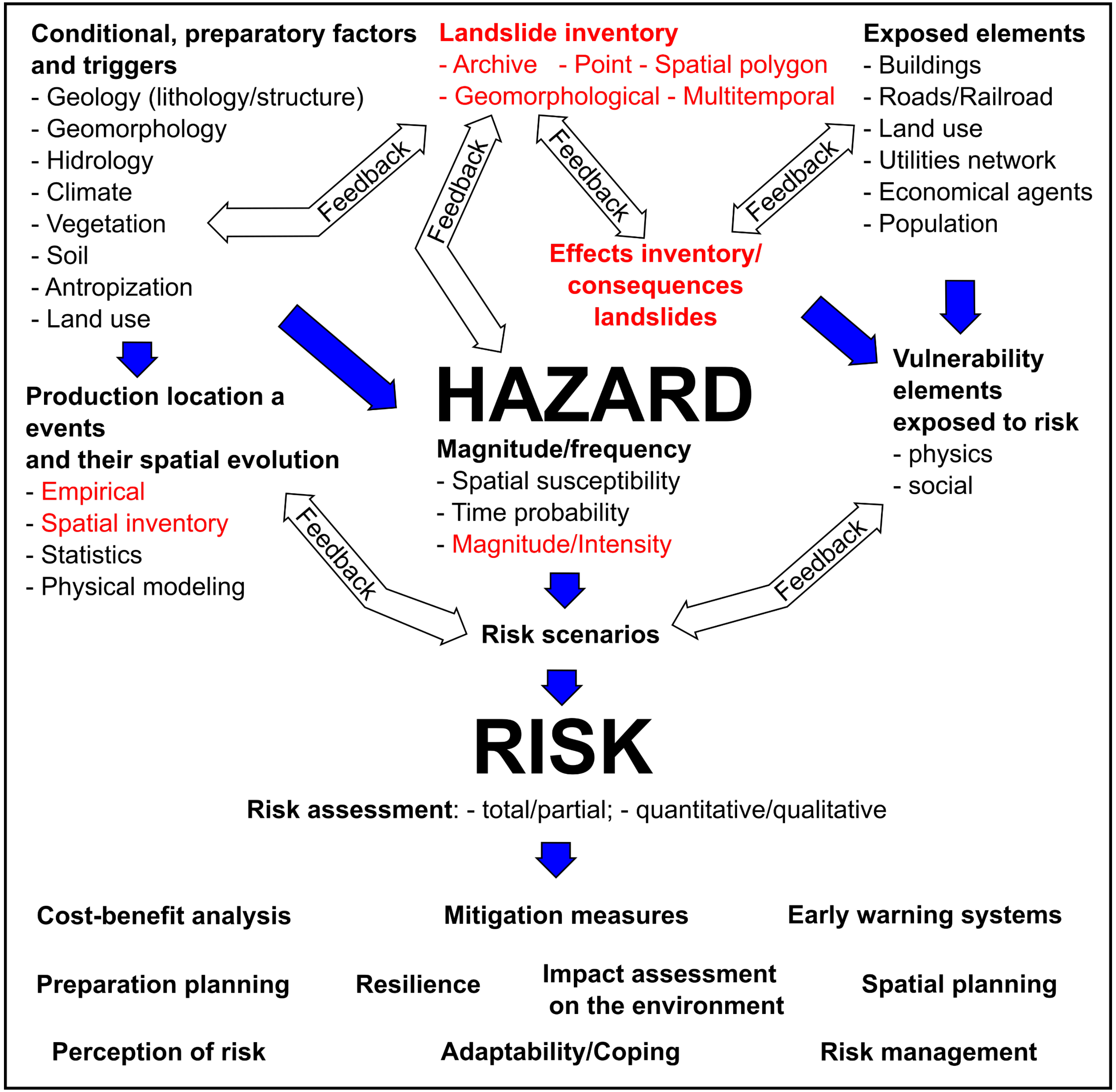
Los Angeles City Council has restricted the size of the houses in the area.

Phase I consisted of winterization of the slope by removal of the destroyed homes, surface regrading and drainage control, dewatering, removal of slide debris in the Bluebird Canyon drainage, installation of a storm drain, construction of a gravity buttress in the canyon, and stabilization of the headscarp with a temporary tieback /shoring wall. This work was fast-tracked and required constant coordination between the design and contracting teams to respond to difficult field conditions.

Phase II included removal of the majority of the landslide mass, construction of two soil-cement shear keys, placement of a subdrain network, and placement of engineered fill to rebuild the slope.

Hazard & Risk vs. Disaster

- The hazard is defined as the probability in time and space o have a certain phenomenon happening.
- The risk is defined as the probability in time and space to have a loss (life or material) as a consequence of a hazard.
- The elements exposed to the hazard and their vulnerability to the hazard will help estimate the risk.



- Because of the complexities of the components involved, the hazard-to-risk chain is approached considering scenarios and hazard magnitudes (think about earthquakes for example, and their magnitude).

- Disasters are actual hazard events that generate huge losses (economic & causalities) that greatly affect society; the risk becomes a reality during a disaster, and these unforeseen events can be used to validate/train risk evaluation.

- These concepts, are used in order to understand better the natural phenomenon and their relation with society, with the final goal to increase the resilieof increasingnce; while these natural events cannot be stopped, we speak about their mitigation.

Mitigation strategies for control of urban landslides

- Given that urban landslides create human life loss and economic, the mitigation strategies for their control is a hot topic (Schwab et al., 2005; Schuster and Highland, 2006)
- Early Warning Landslide System can reduce the life loss, but do not reduce damage to infrastructure. Only planning based on the hazard and risk assessment can reduce the material damage, but this is also sometimes hard to be implemented due to socio-political issues.
- Due to the pulsatory frequency of these events, the danger posed is easily forgotten, or the sense of urgency is not so obvious.
- Often, the temporal frequency of landslide events is underestimated and the hazard can be also underestimated.

Key planning issues for development in urban areas

Lack of landslide insurance tends to push affected home and business owners to seek restitution for landslide losses from local governments, especially if they feel they can make a case that local officials were negligent in permitting or inspecting the failed development.

This raises the following questions (Schwab et al. 2005):

• How much responsibility does local government bear for ensuring that development in landslide-prone areas is safe?

• What level of risk does the property owner assume in choosing to live or do business in a high-risk area?

• What is the builder's responsibility for ensuring that the slope remains stable?

• Is the local government responsible for educating property owners on issues such as proper landscaping and water usage?

It is important to stress that, although it is possible to provide engineering solutions in landslide-prone areas, these solutions are often expensive and may be risky (Schwab et al. 2005).

Even with the best engineering methodology, and in spite of the best intentions, grading may not be done exactly as specified, construction mistakes may be made and slopes may still be de-stabilized.

Thus restricting or prohibiting development in landslide-prone areas may often remain the wisest option for loss mitigation, in spite of pressures to the contrary.

Major policy options for landslide hazard mitigation in urban areas

Three basic options are available to decision-makers who are confronted by landslide hazards in urban areas (Schuster 1991; Schuster and Kockelman 1996):

1. Take no action, either before or after the landslide activity,

2. Provide relief and rehabilitation efforts after the landslides occur, or

3. Using mitigative action, avoid or prevent landslides before serious damage occurs.

Prior to about 1950, the first two of these options prevailed. However, since that time and as the result of sociological and technical advances, the concept of prevention of urban landslide disasters by land use management or physical mitigative measures has become

Pre-requisites for mitigation of urban landslide hazards

Successful urban landslide hazard reduction programs are most commonly based on ready availability of the following (US Geological Survey 1982):

(a) Technical information related to the hazards and risks posed by landslides in the area. These can consist of: (1) digital information, including images, landslide inventories and geological maps and reports; (2) non-digital information, including hard copies of images, inventories, maps and reports (3) reports on technical research, loss estimation, and application of remedial measures; (4) data from real-time monitoring of slopes; (5) weather information and hazard alerts; and (6) manuals, videos and other training materials (Committee on the Review of the National Landslide Hazards Mitigation Strategy 2004).

(b) A technical community of geologists, engineers and urban planners who are able to utilize, and enlarge upon, this data base;

(c) A concerned and able municipal government; and (d) An urban population that realizes the value of and supports the hazard reduction program.

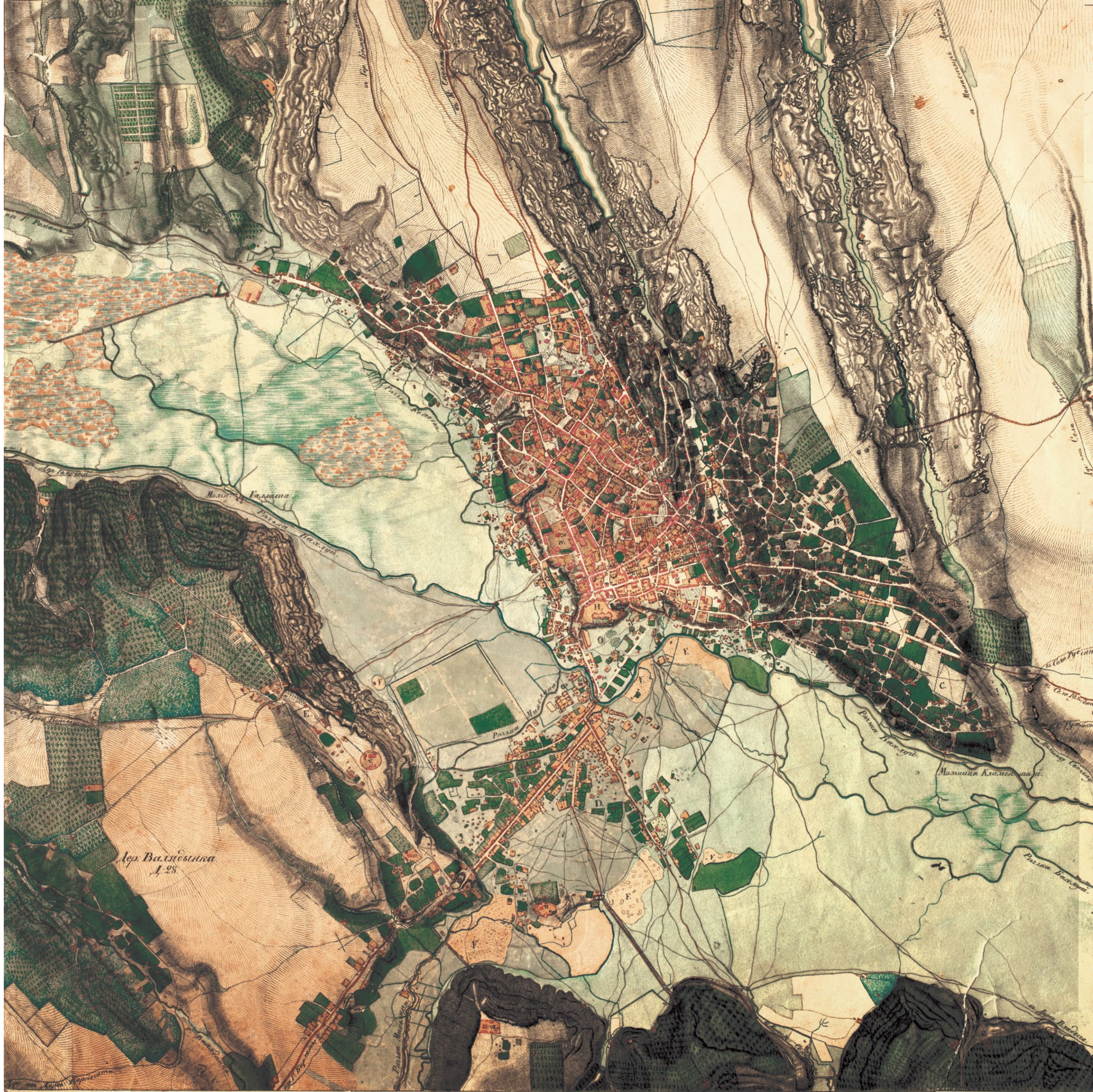
Historical landslide inventories provide some of the most crucial information in the hazard identification phase of the urban planning process. Landslide hazard maps are especially important as pre-requisite information.

In addition, the development and use of geographic information systems (GIS) has played an increasingly prominent and valuable role in hazard mapping and mitigation. Table 1 illustrates many of the data types that geologists can provide, and planners should use, in pursuing the common goal of landslide loss reduction. Once this information is incorporated into a local GIS, planners can use it to analyze various data layers and make informed decisions about acceptable land uses and the risks they may entail (Schwab et al. 2005). In addition, recent development of high-resolution digital elevation mapping using Light Detection and Ranging (LIDAR) is also proving valuable for landslide detection and mapping, especially in wooded areas where pre-existing landslides are often difficult to recognize.

1. Restricting development in landslide-prone urban areas, a function assisted by mapping landslide susceptibility;
2. Requiring (by means of codes) that grading, excavation, landscaping, construction, vegetation clearance, and drainage activities not contribute to slope instability;
3. Protecting existing developments and population by physical mitigation measures, such as slope geometry modifications, drainage, counterfort berms that serve as buttresses, and protective barriers;
4. Development and installation of monitoring and warning systems.

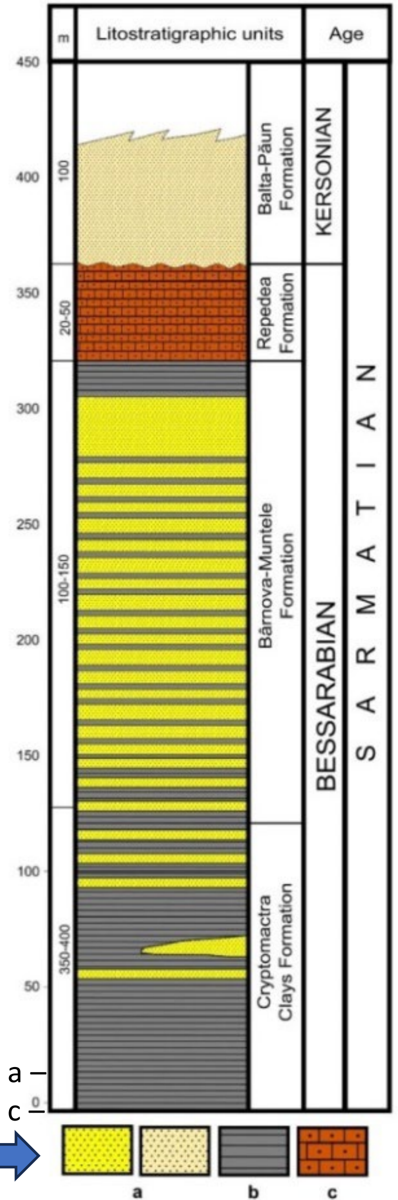
Iasi Municipality study case: NW Copou hillslope

- Iași Municipality overlays several slow-moving landslides.
- These landslides are old, from different periods of the Holocene.
- Historically, as the city spread along the Copou Hill plateau, the landslides on the NW hillslope reactivated.
- In archives there are medieval mentions of churches affected by landslides that were moved on the plateau (and the name was changed with the attribute from the valley with from the hill).



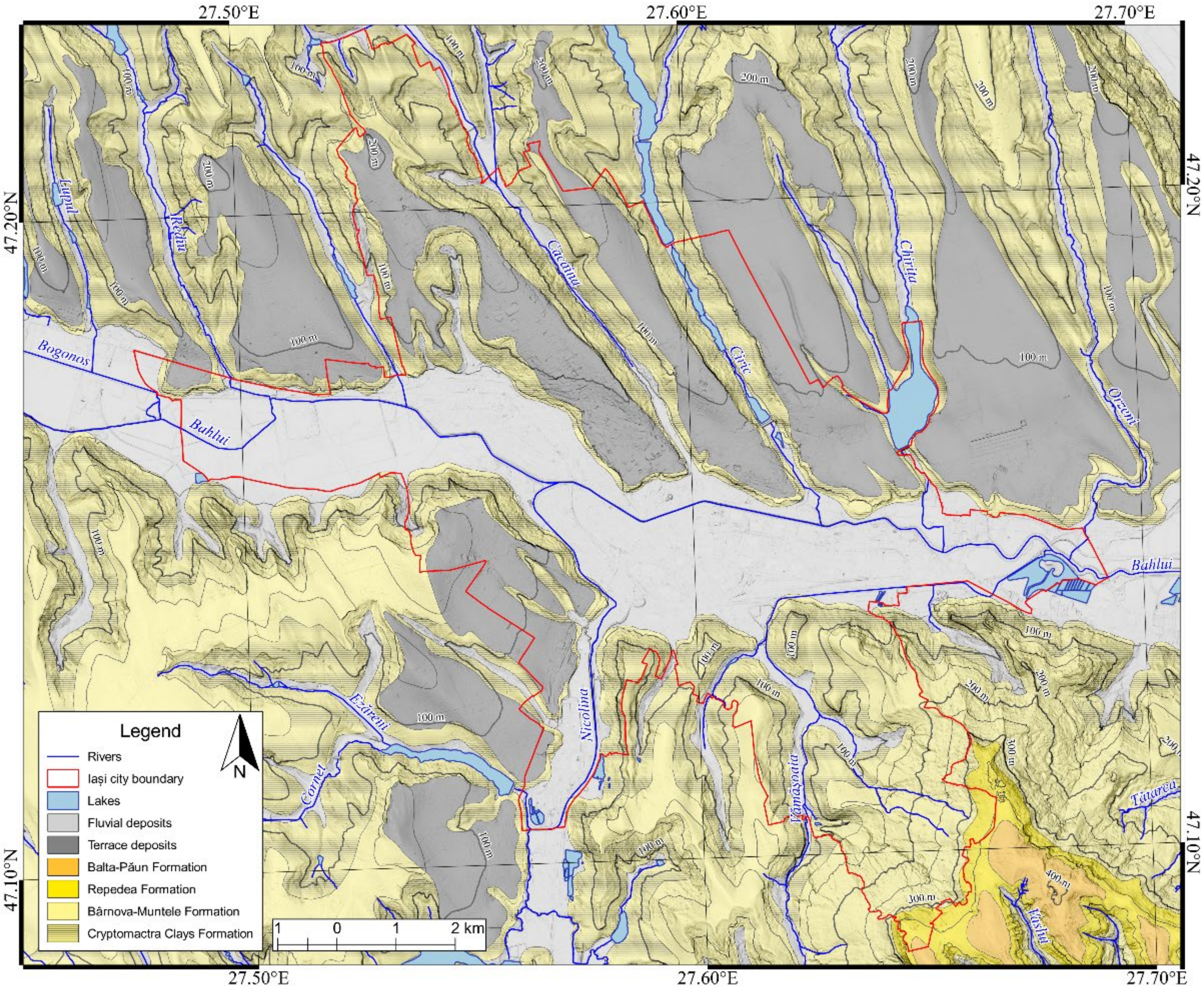
Iași Municipality

- located in the north-eastern part of Romania;
- hilly area (Jijia Hills) dominated by cuesta landforms and asymmetric valleys.
- gentle monoclinic structure dipping towards south-east
- mudstone-dominated lithology interbedded by sandy layers that were accumulated during the Middle Miocene
- quaternary deposits: alluvial, slope, terrace, ridge, loess
- susceptible to landslide reactivations.



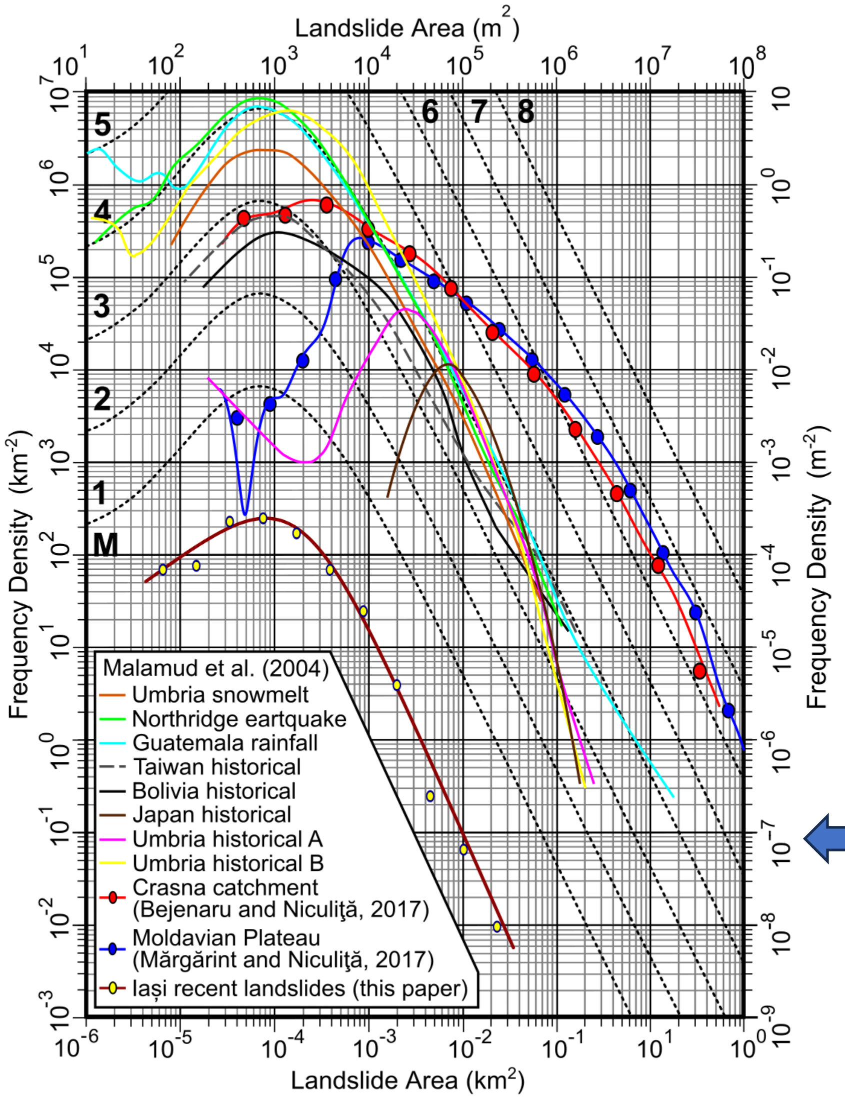
Lithostratigraphic column of the area: a – sands, b – claystones and mudstones, c – limestones.

Geology of Iași Municipality and its surroundings.



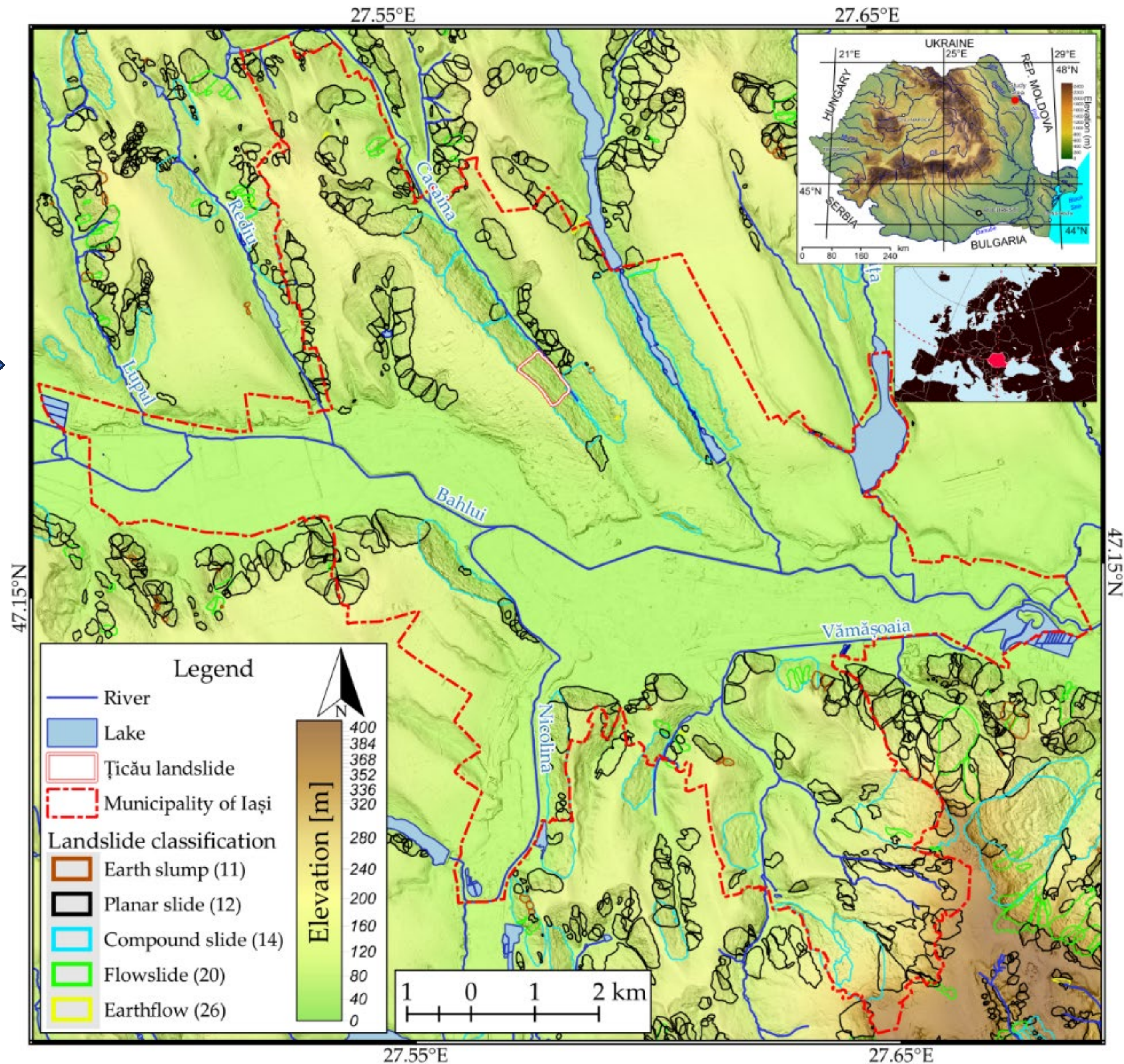
Iași Municipality

- Located in the North-Eastern part of Romania, at the contact between Jijia Hills and Central Moldavian Plateau
- Crossed by Bahlui River from West to East
- The northern part of the city comprises hills with altitudes small, up to 200 – 220 m, and the southern part is defined by steeply sloping hills with altitudes of up to 404 m above sea level
- They face problems caused by the presence and reactivation of landslides.



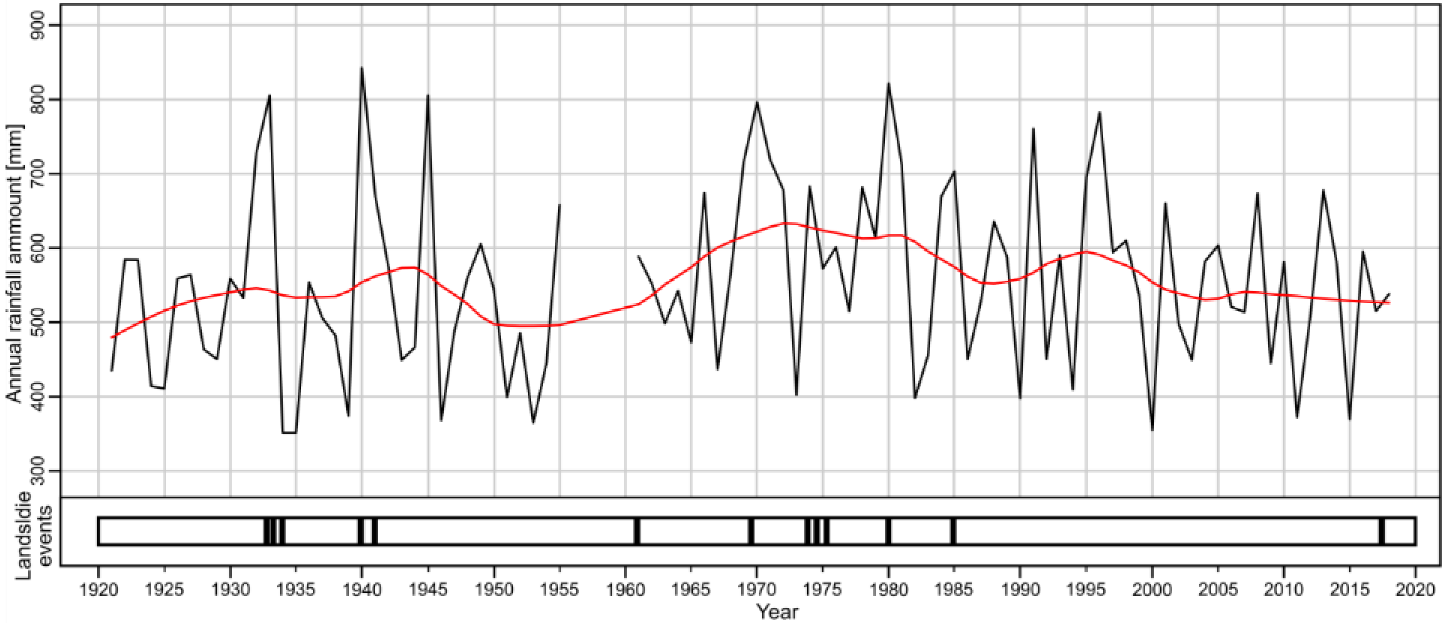
Frequency-magnitude relation for the mapped geomorphological inventory.

Location of Iași Municipality and the geomorphological landslide inventory of the area.

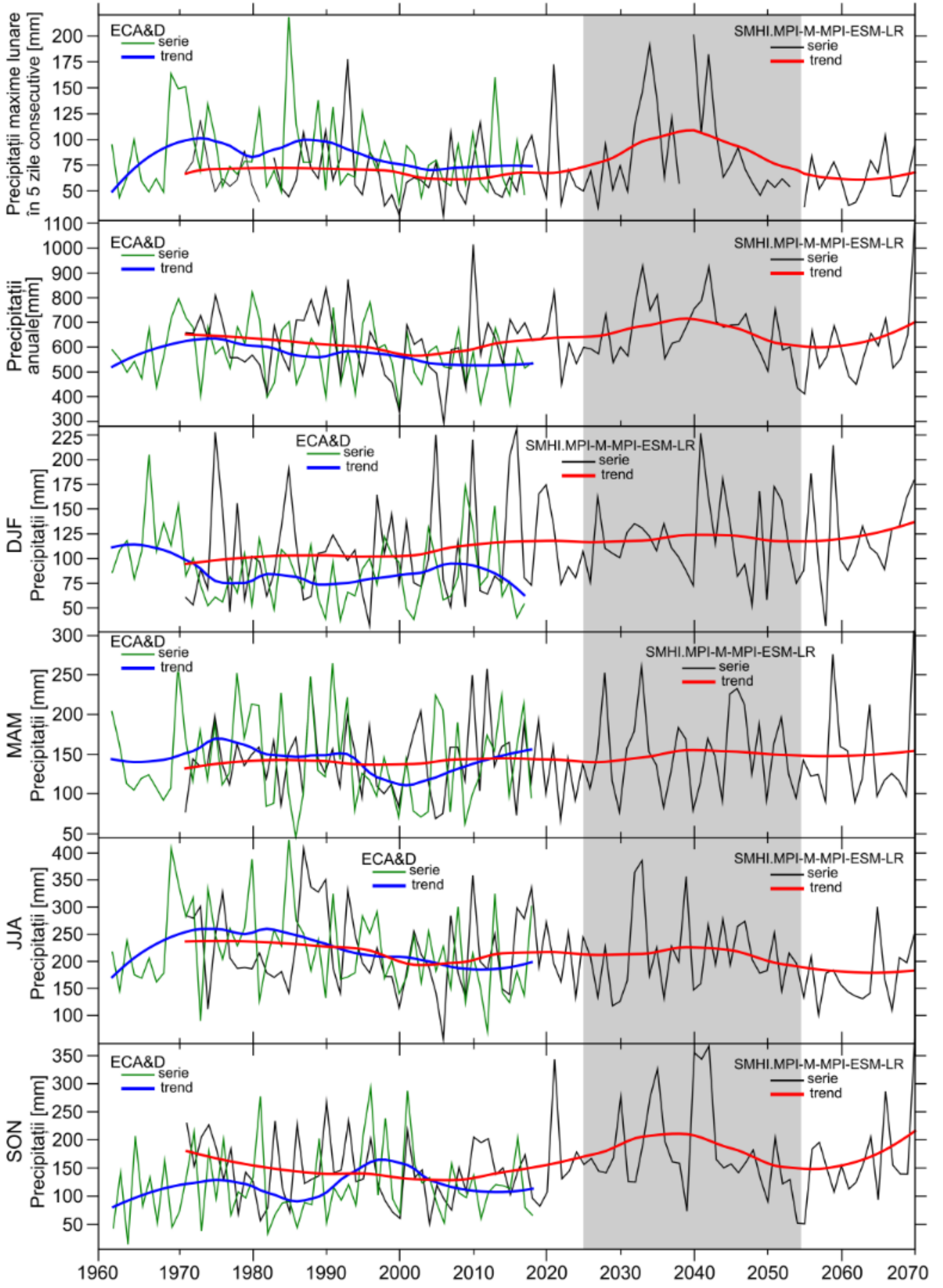


Rainfall amount

- The dry climate of the area is characterized by average annual precipitation of 530 mm/year.
- The distribution of rainfall during the year is much more important.
- The rainy periods of 1920–1950 and 1960–2000 could indicate a wet cycle of 30–40 years.
- Empirical rainfall evolution models predict a return to a ~30-year wet cycle that will lead to an increase in the frequency of landslides.

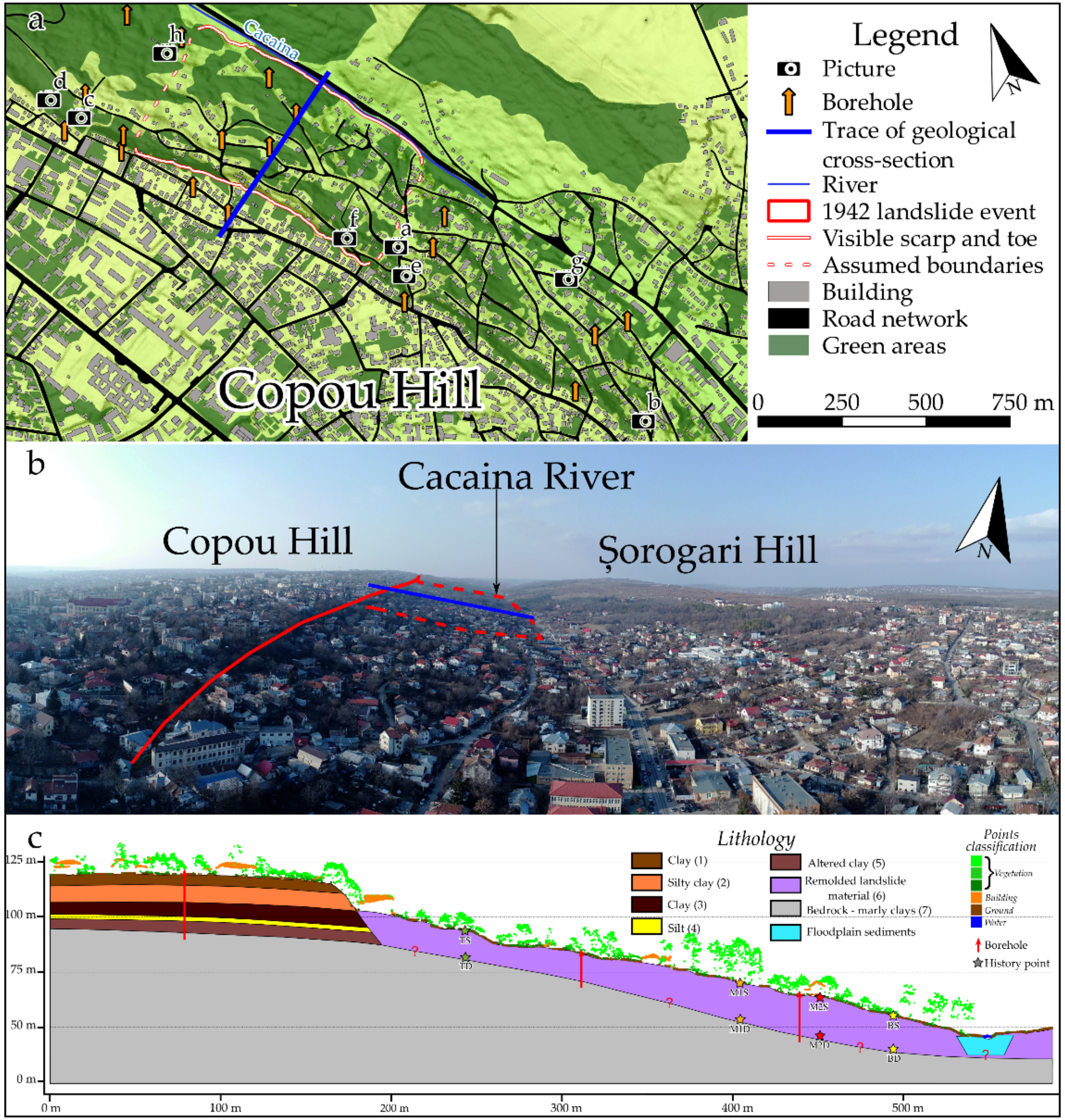


Mean annual rainfall for the Iași meteorological station since 1921.



Climatic forecast of various rainfall indices up to 2070.

Landslides of Iași



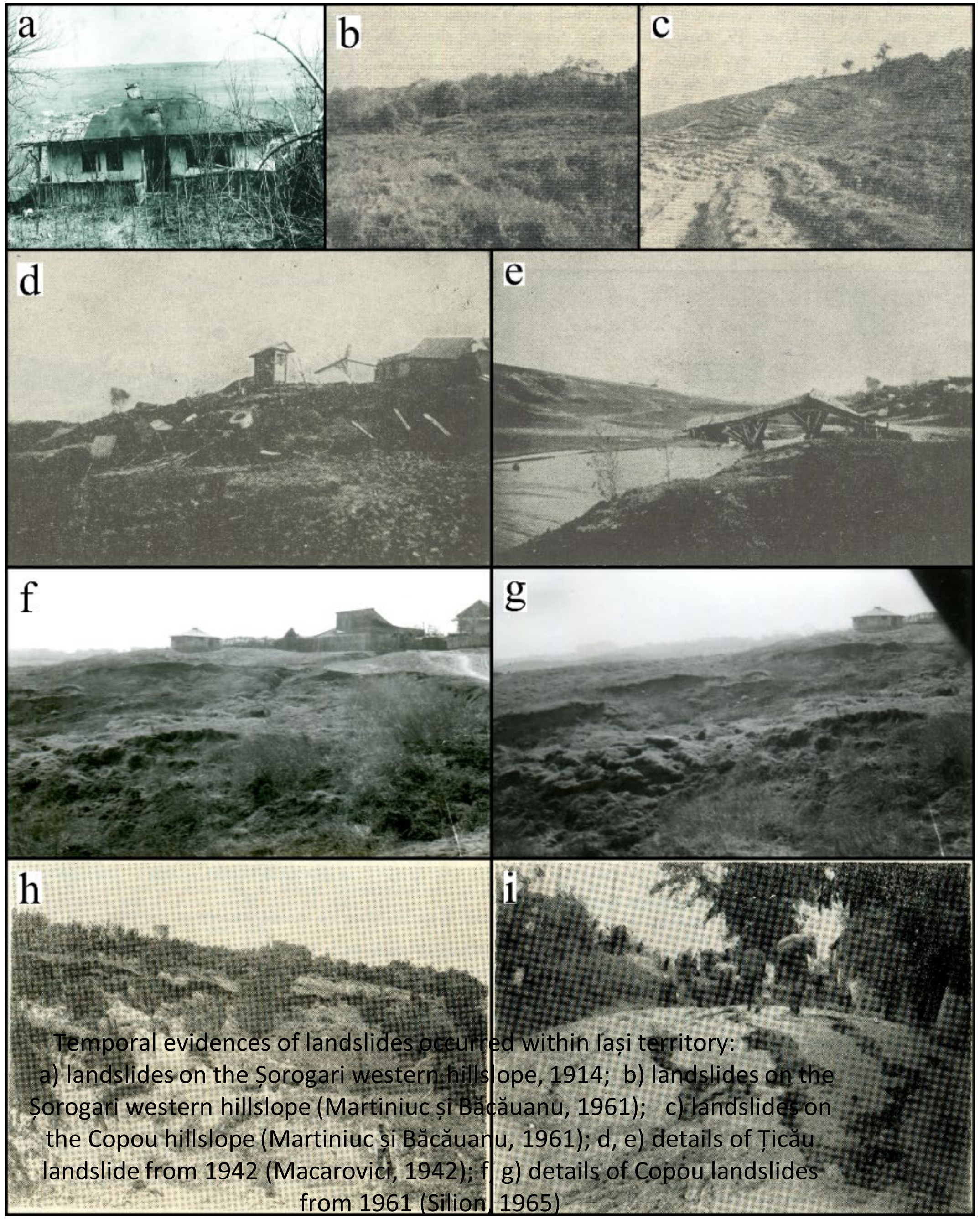
Țicău slow-moving landslide affecting the Țicău neighborhood.

Road affected by landslides, Galata neighborhood, 2013.

Ursulea landslide scarp after 2017 reactivation.

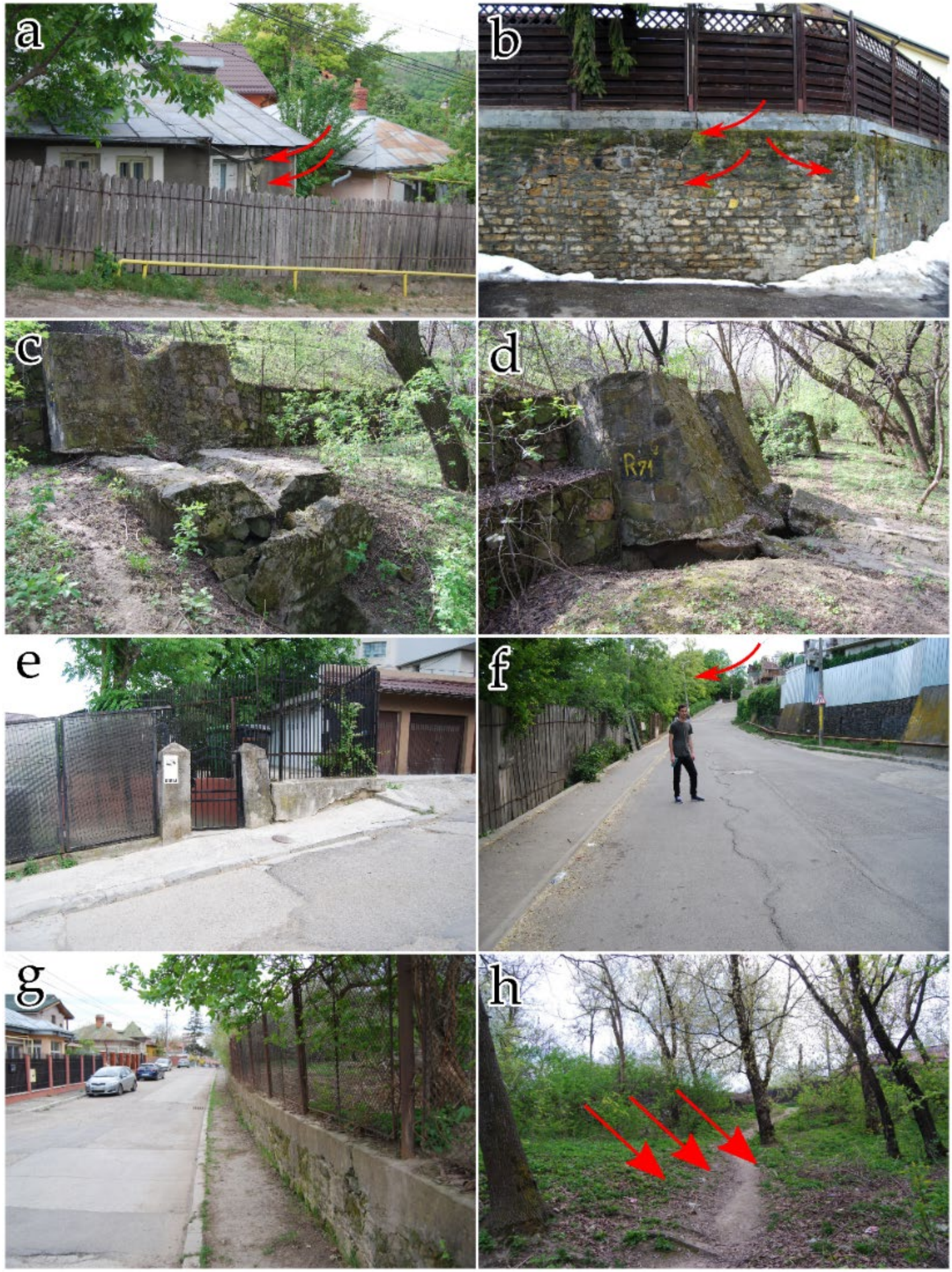
Ursulea landslide development from 2013 until its 2017 reactivation.

Landslides of Iași



Temporal evidences of landslides occurred within Iași territory:
a) landslides on the Șorogari western hillslope, 1914; b) landslides on the Șorogari western hillslope (Martiniuc și Băcăuanu, 1961); c) landslides on the Copou hillslope (Martiniuc și Băcăuanu, 1961); d, e) details of Țicău landslide from 1942 (Macarovici, 1942); f, g) details of Copou landslides from 1961 (Silion, 1965)

Evidence of landslide activity within Țicău neighborhood.



Geological engineering

- Between 1960 and 1980 the following measures were taken:

- Improvement of surface and subsurface drainage, with drainage ditches and sewage pipes, to evacuate the water in the local tributary;
- Buttressing of the major scarp and the minor scarps;
- Building piles and retaining walls, especially along the main roads;
- The unhabituated hillslope was forested with oak;
- Building construction was stopped (until 1989).

- After 1989:

- Previous engineering works were not maintained;
- Drainage improvements were destroyed;
- New building construction was allowed.

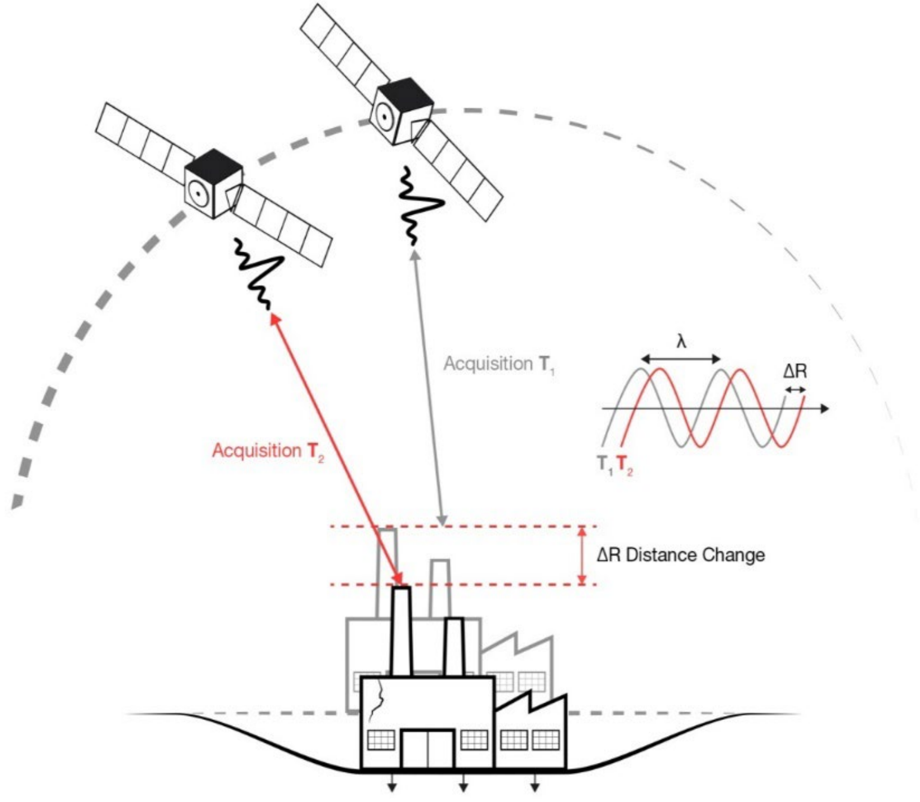
InSAR technique

SAR – Synthetic Aperture Radar

Aperture = satellite antenna – used to synthetize the backscattered echoes to increase the resolution of the resulting image despite a physically small antenna

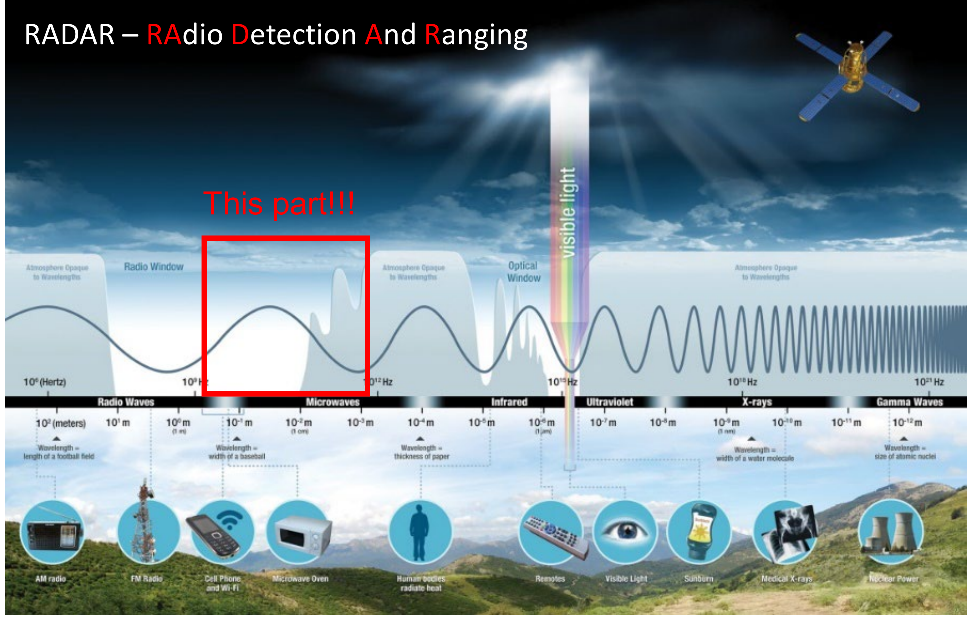
Interferometry/InSAR = how much and how fast is the ground surface moving?????!!!!!

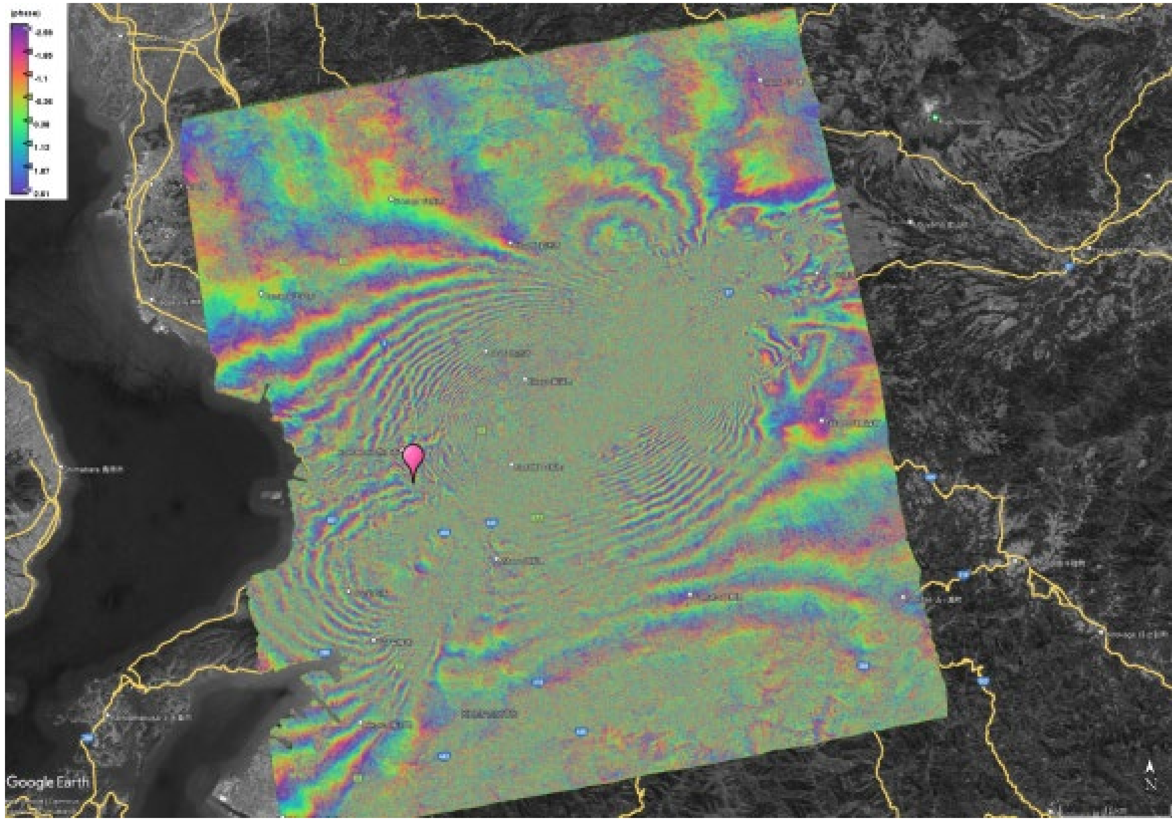
Interferogram = the difference of phase values between 2 SAR acquisitions corresponding to a certain area.



Principle of InSAR

Electomagnetic spectrum





Co-seismic interferogram of Kumamoto Earthquake, Japan, 2016.

MT-InSAR

PSI techniques ⇔ **MTI techniques** ⇔ **A-DInSAR techniques**

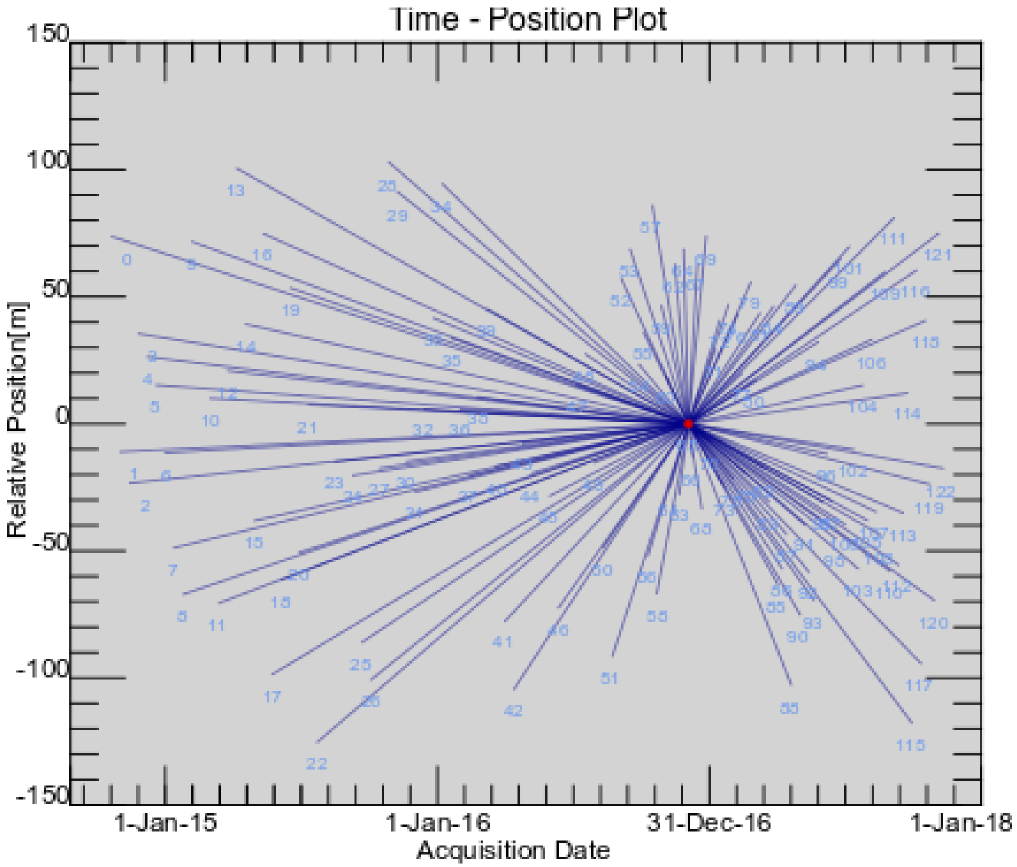
(Crosetto et al., 2016) **(Wasowski and Bovenga, 2014)** **(Necula et al., 2017)**

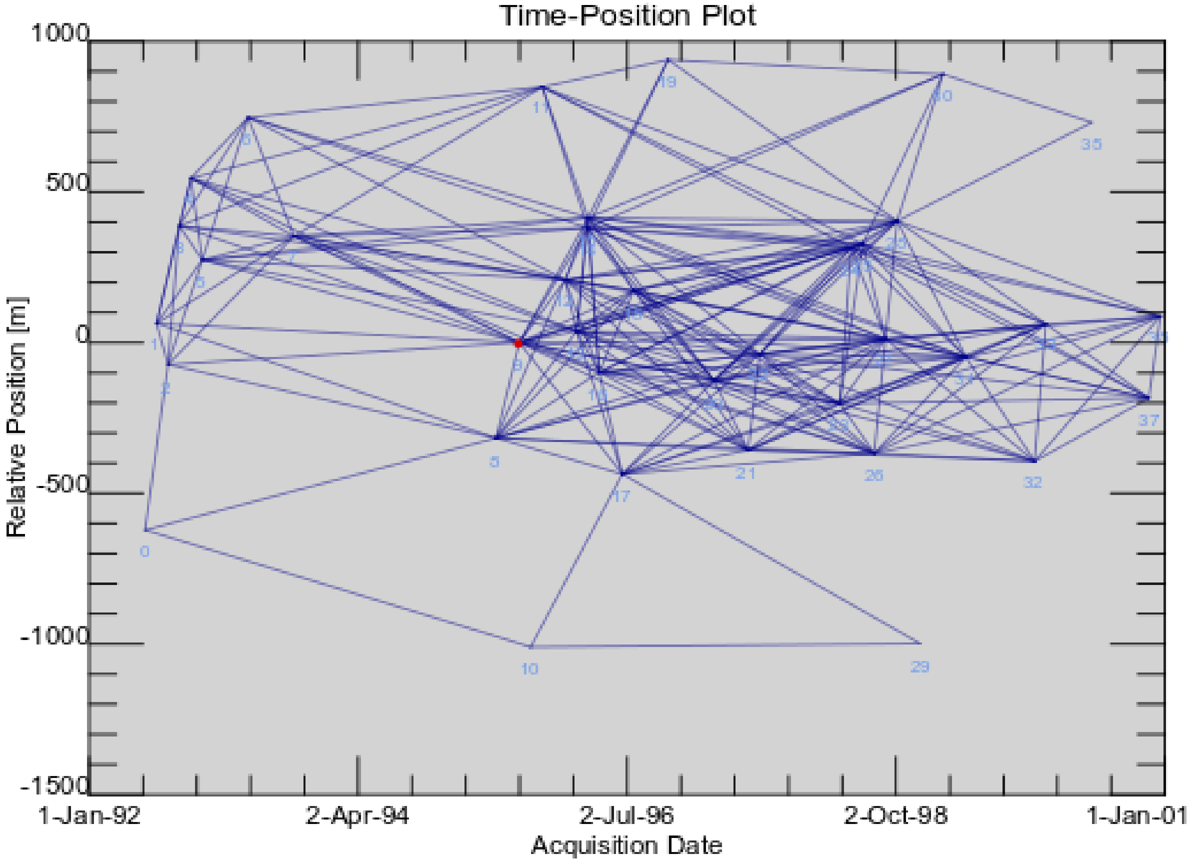
PSI techniques – Persistent Scatterer Interferometry
MTI techniques – Multi Temporal Interferometry
A-DInSAR techniques – Advanced Differential SAR Interferometry

Two types of techniques:

- that exploits Permanent Scatterers – **PS-InSAR** (Ferretti et al. 2001, 2011; Kampes 2006);

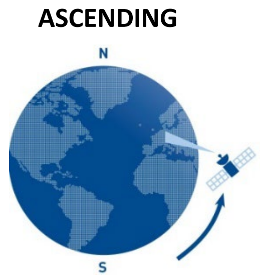
- that uses subsets of images based on small spatial and temporal baselines – **SBAS** (Berardino et al. 2002; Lanari et al. 2007).





Connection graph of SAR images used for interferogram generation: PS-InSAR (left) and SBAS (right)

SAR images and MT-InSAR products



- 19 ENVISAT SAR images, Track 429

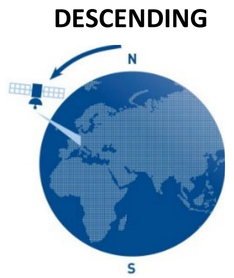
  Time interval: 2002 – 2009;
- 123 Sentinel-1A SAR images, Track 58

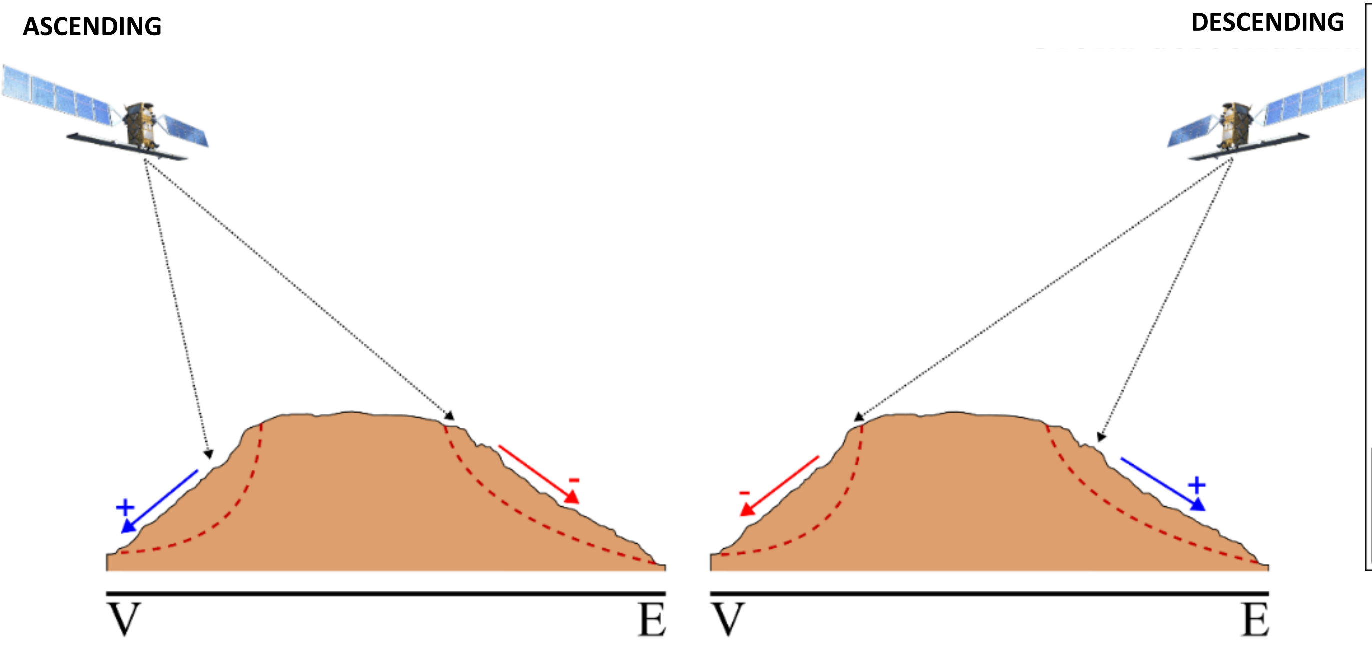
  Time interval: October 2014 – November 2017

- 20 ENVISAT SAR images, Track 193

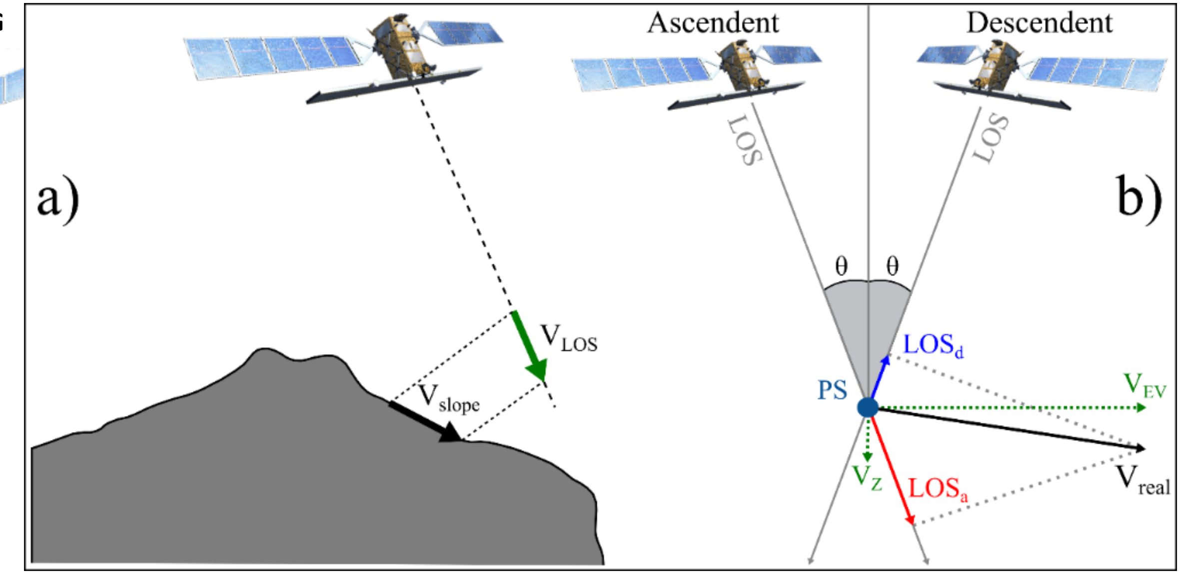
  Time interval: 2003 – 2010;
- 127 Sentinel-1A/B SAR images, Track 109

  Time interval: October 2014 – November 2017



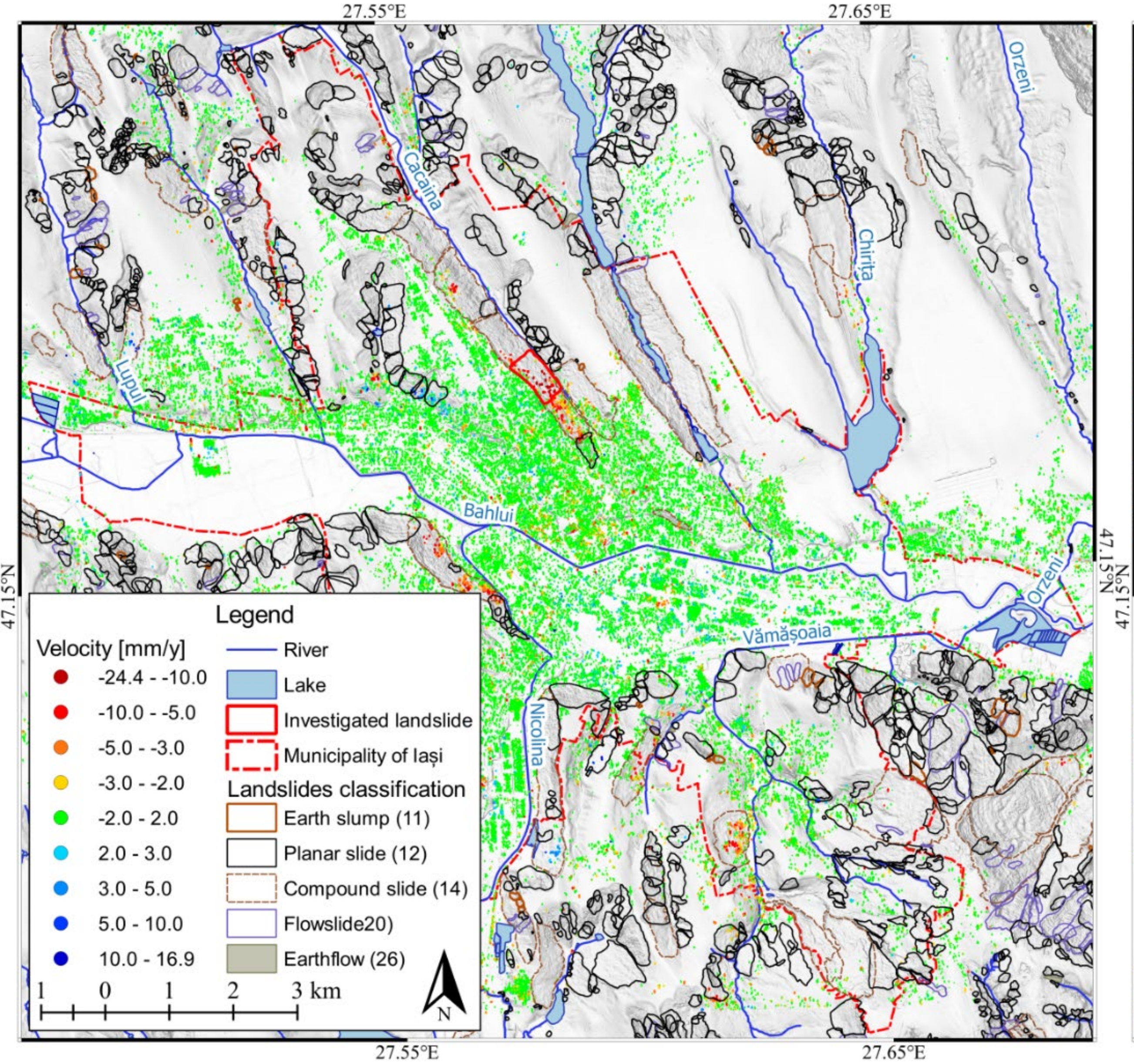


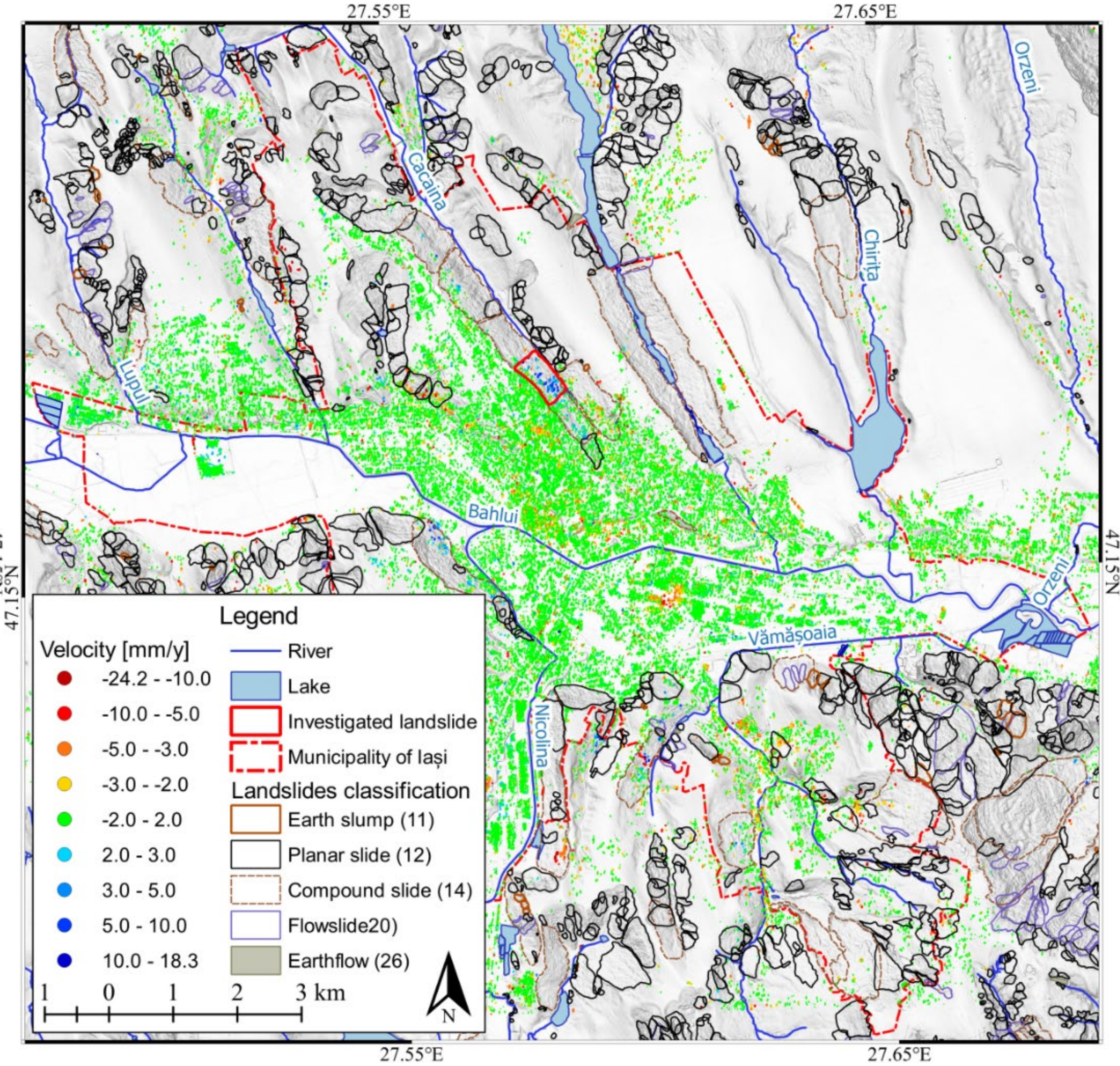
Deformation sketch of ground displacements measured along the Line of Sight



Sketch of LOS measurements projection along the maximum slope (a) and their relation to the vertical and horizontal components of the displacement (b).

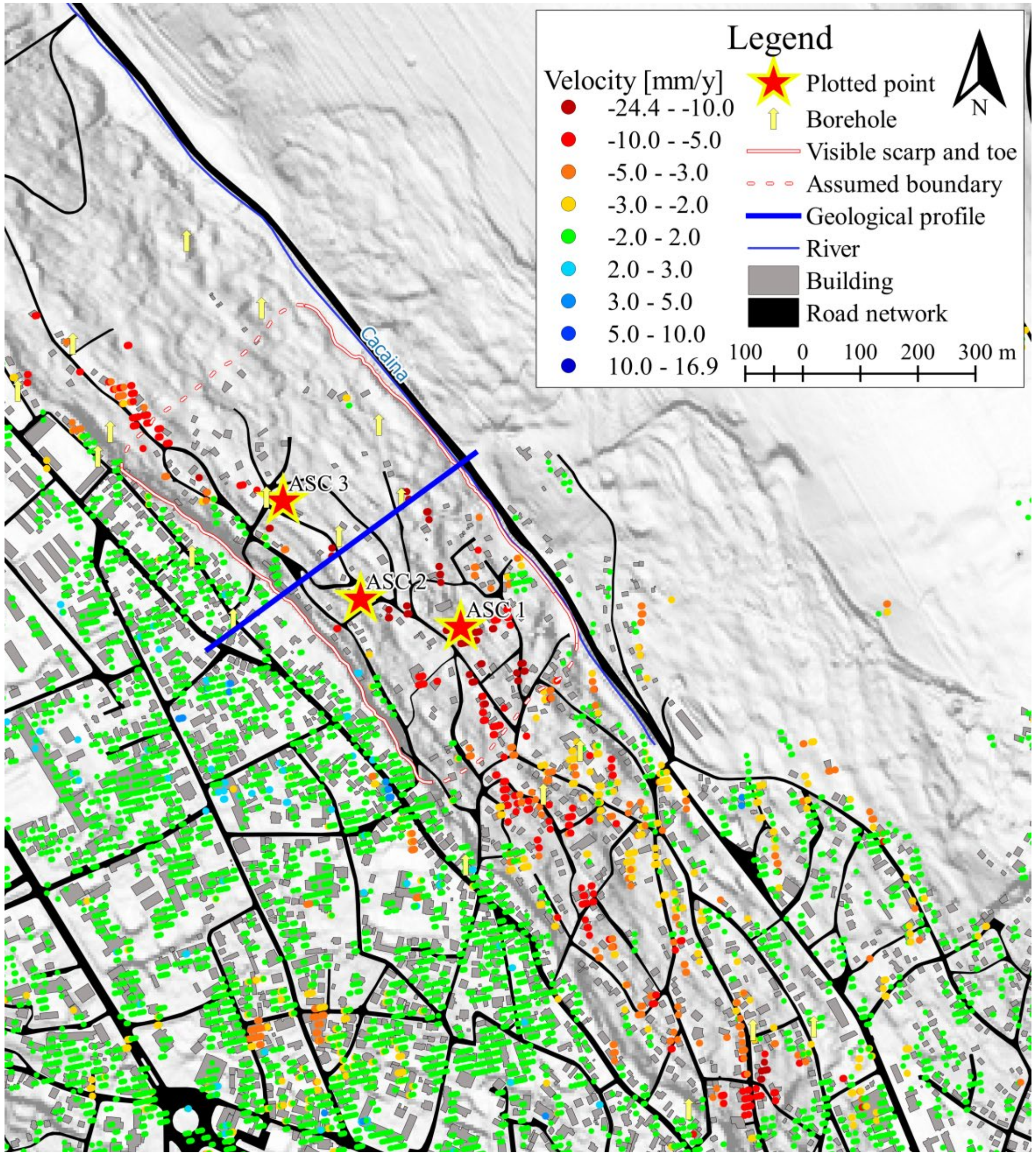
SAR results – velocity maps

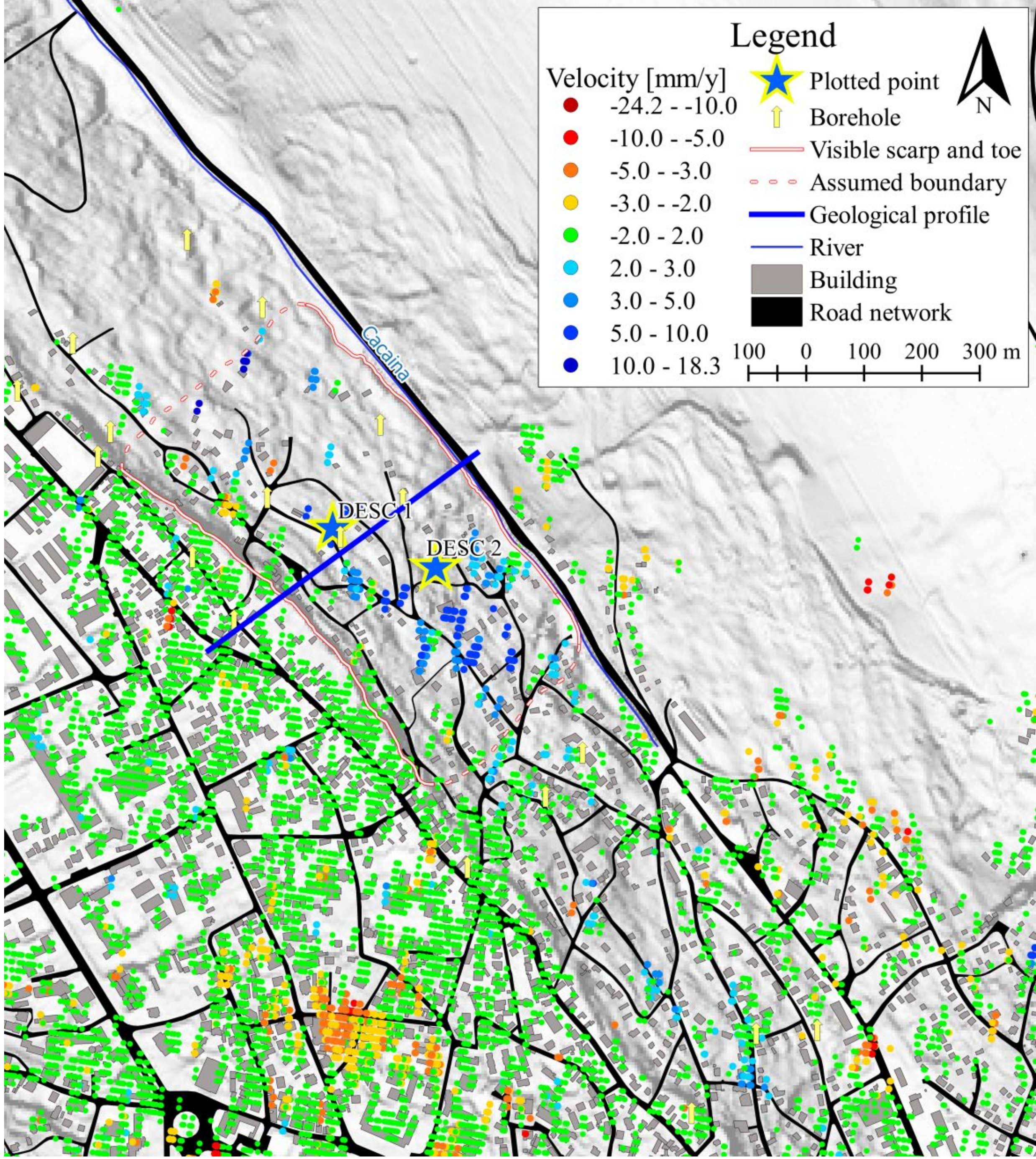




Displacement velocity maps of the Sentinel-1 datasets: ascending (left) and descending (right)

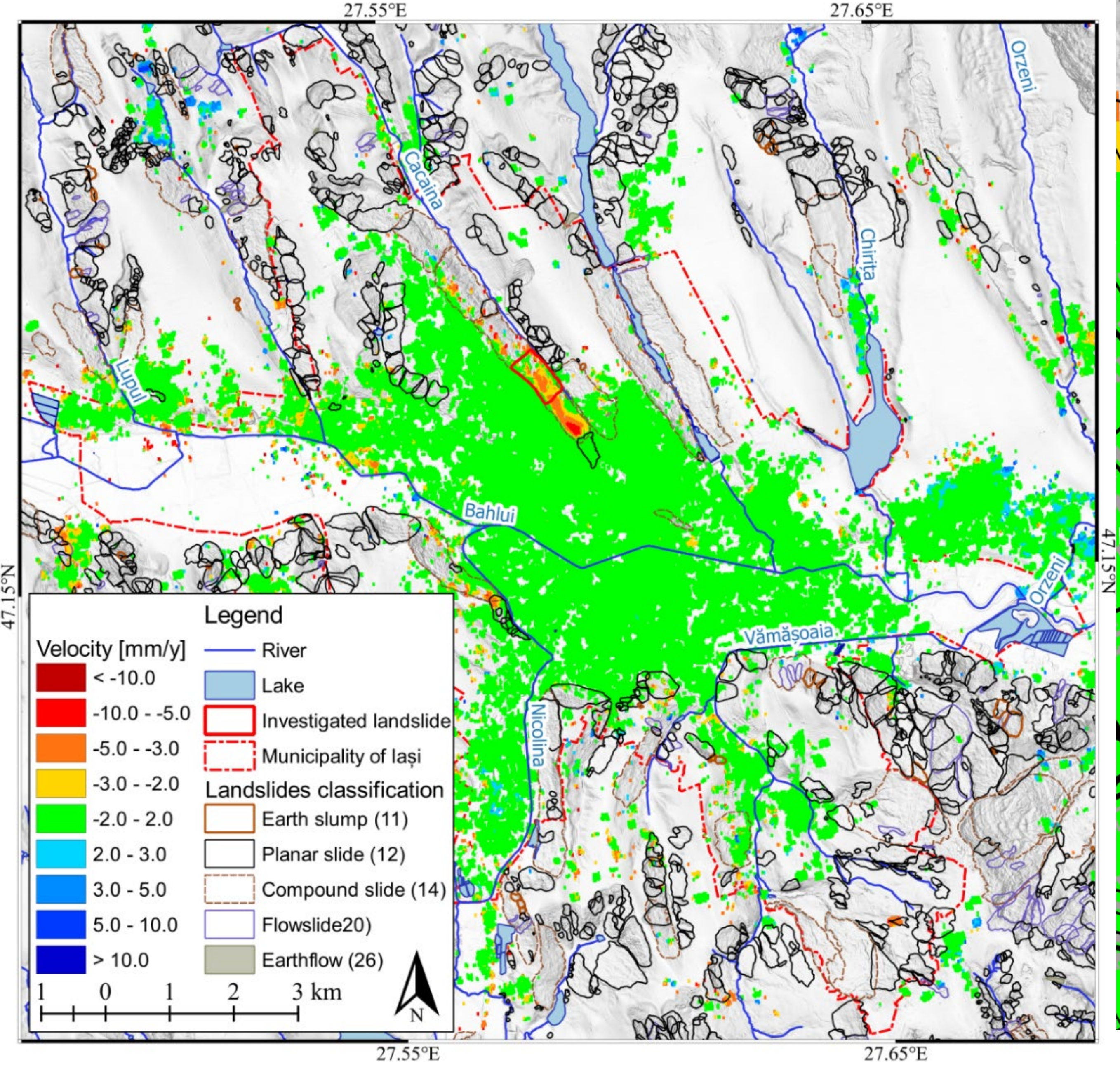
SAR results – velocity maps. Țicău landslide

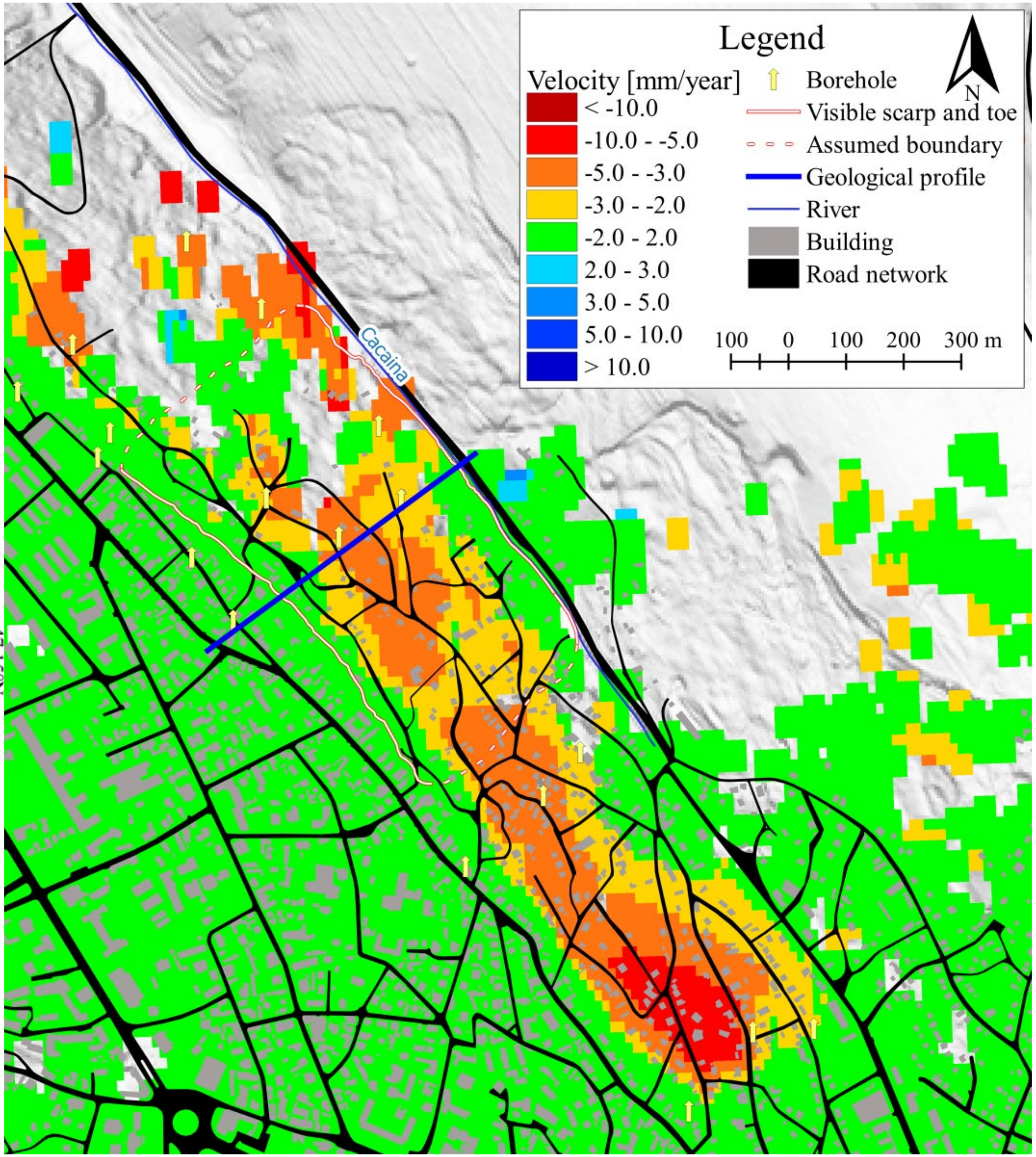




Displacement velocity of Țicău landslide. Sentinel-1 ascending (left) and Sentinel-1 descending (right).

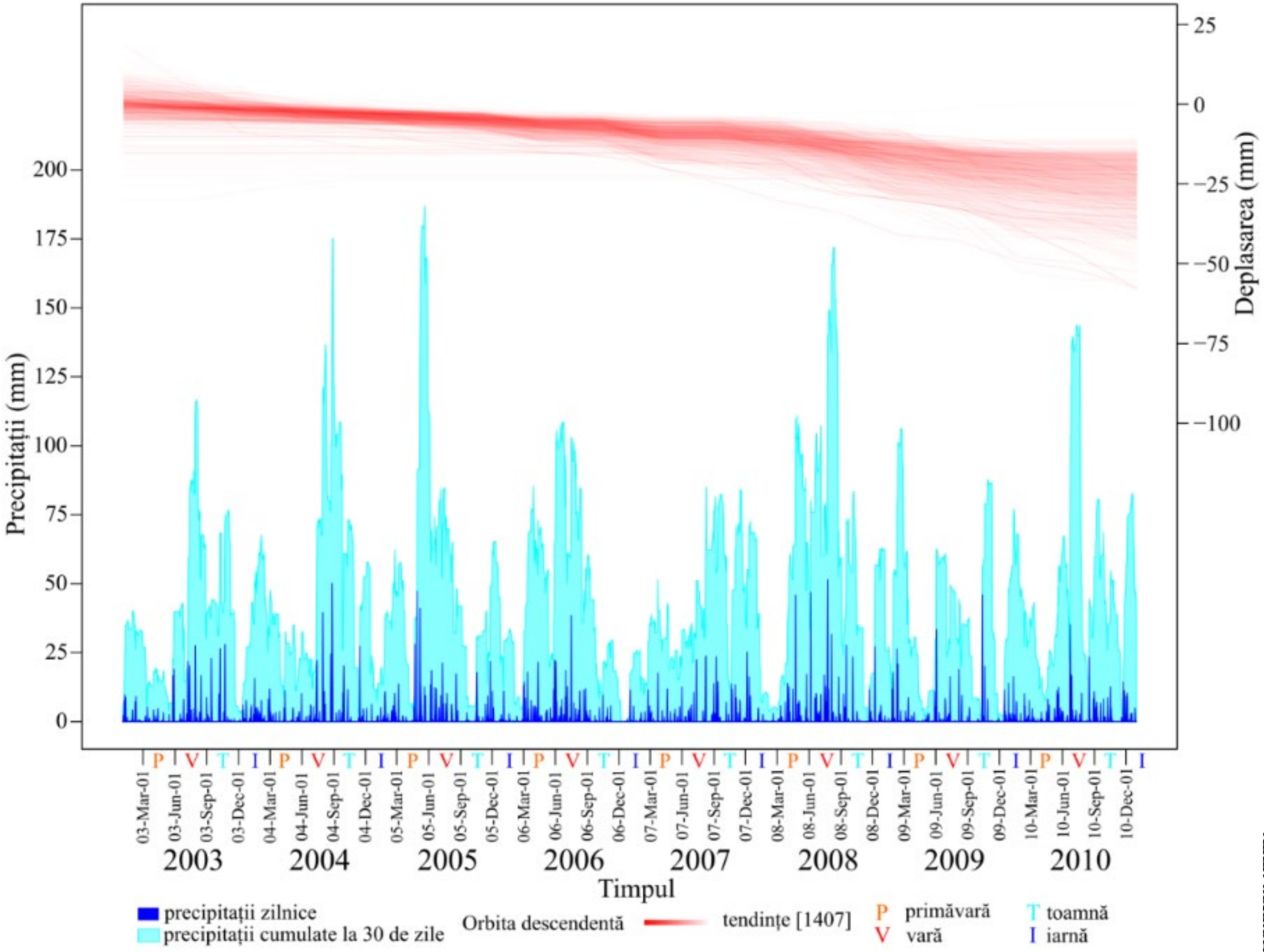
SAR results – velocity maps. Envisat dataset

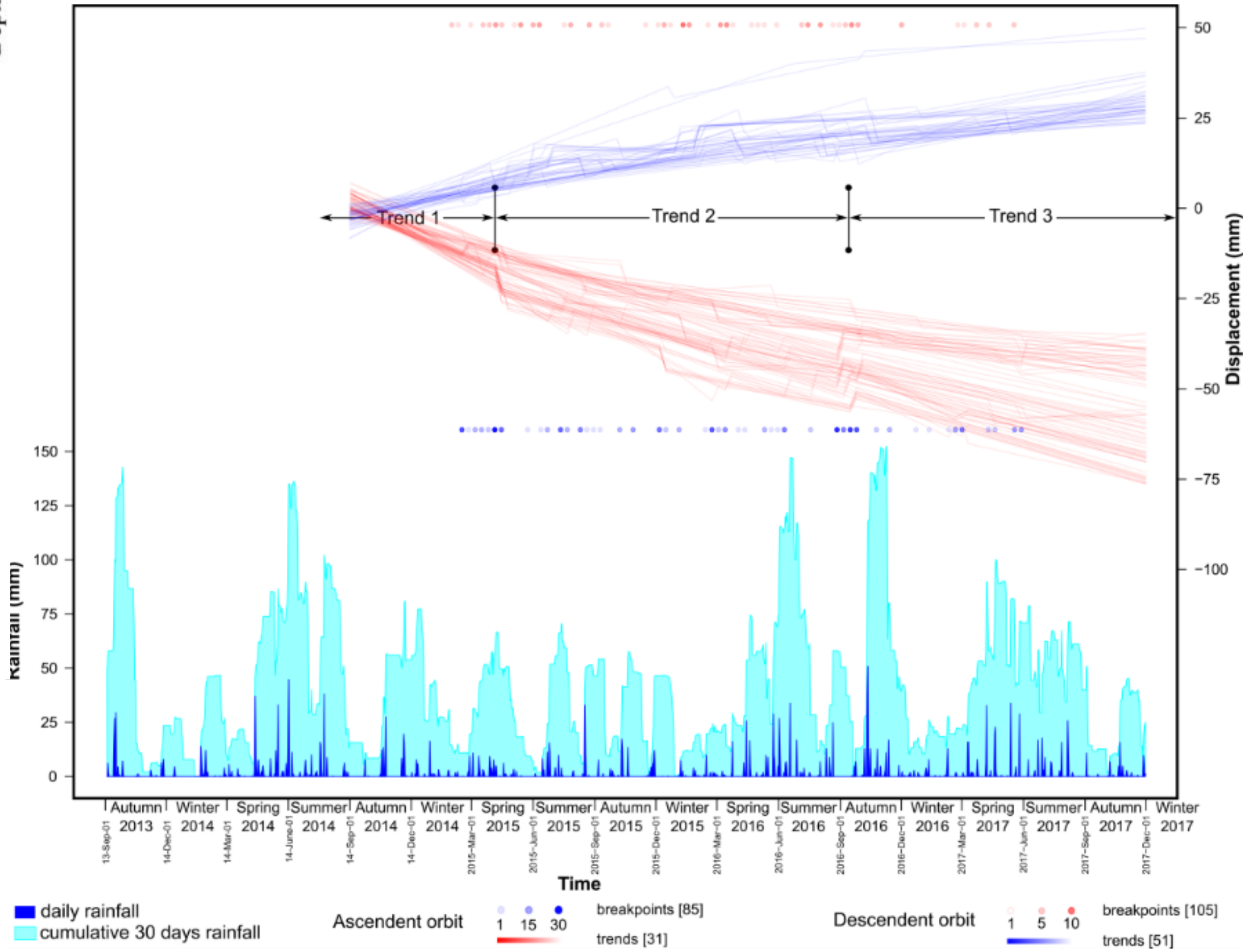




Displacement velocity maps of the ENVISAT ascending dataset for Iași Municipality (left) and Țicău landslide (right).

SAR results – Displacement time series



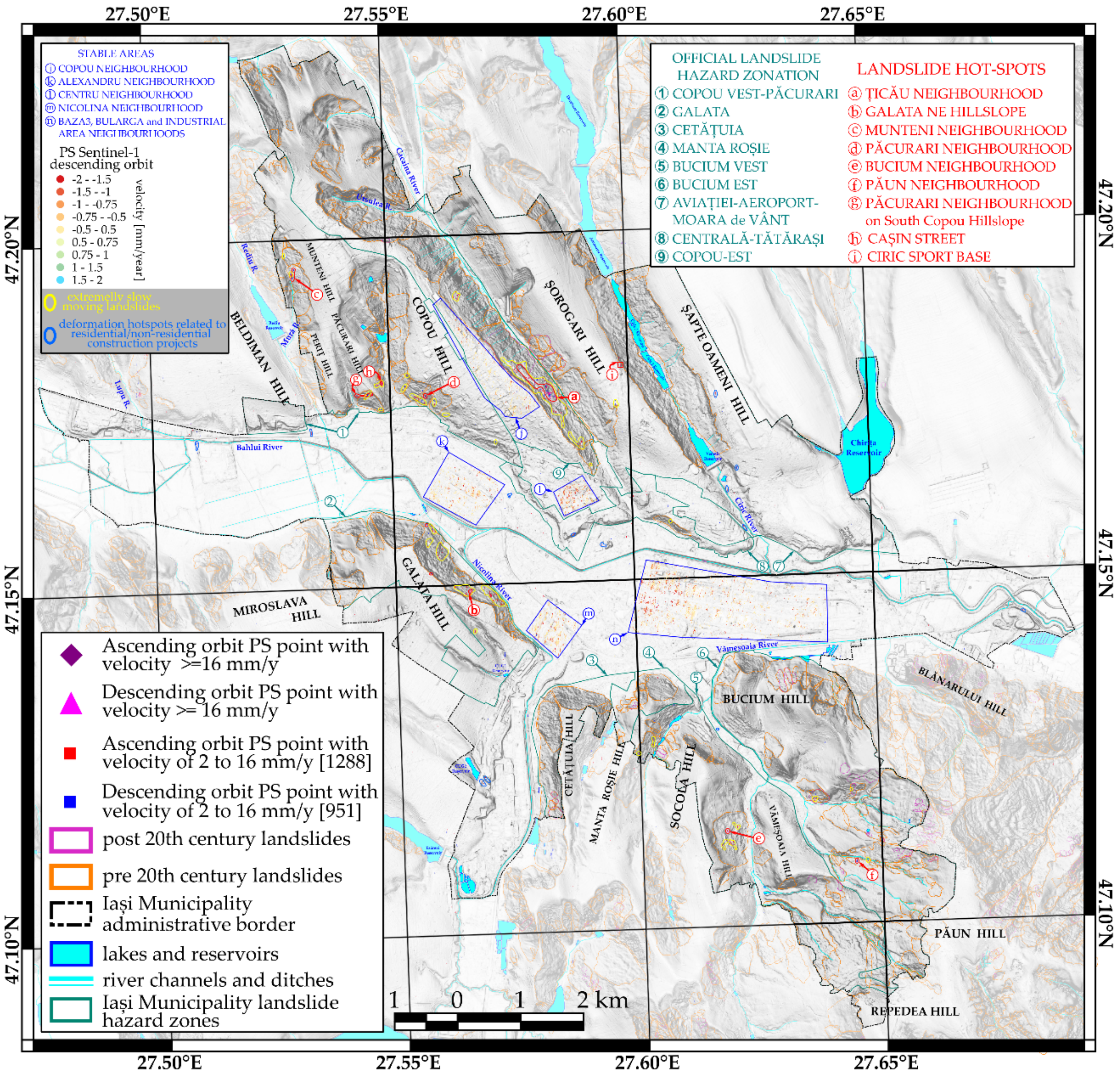


Displacement time series for the ENVISAT ascending dataset (left) and Sentinel-1 datasets (right) and the rainfall amount for the 2003-2017 period.

SAR results – post-processing and landslide hot-spots zonation

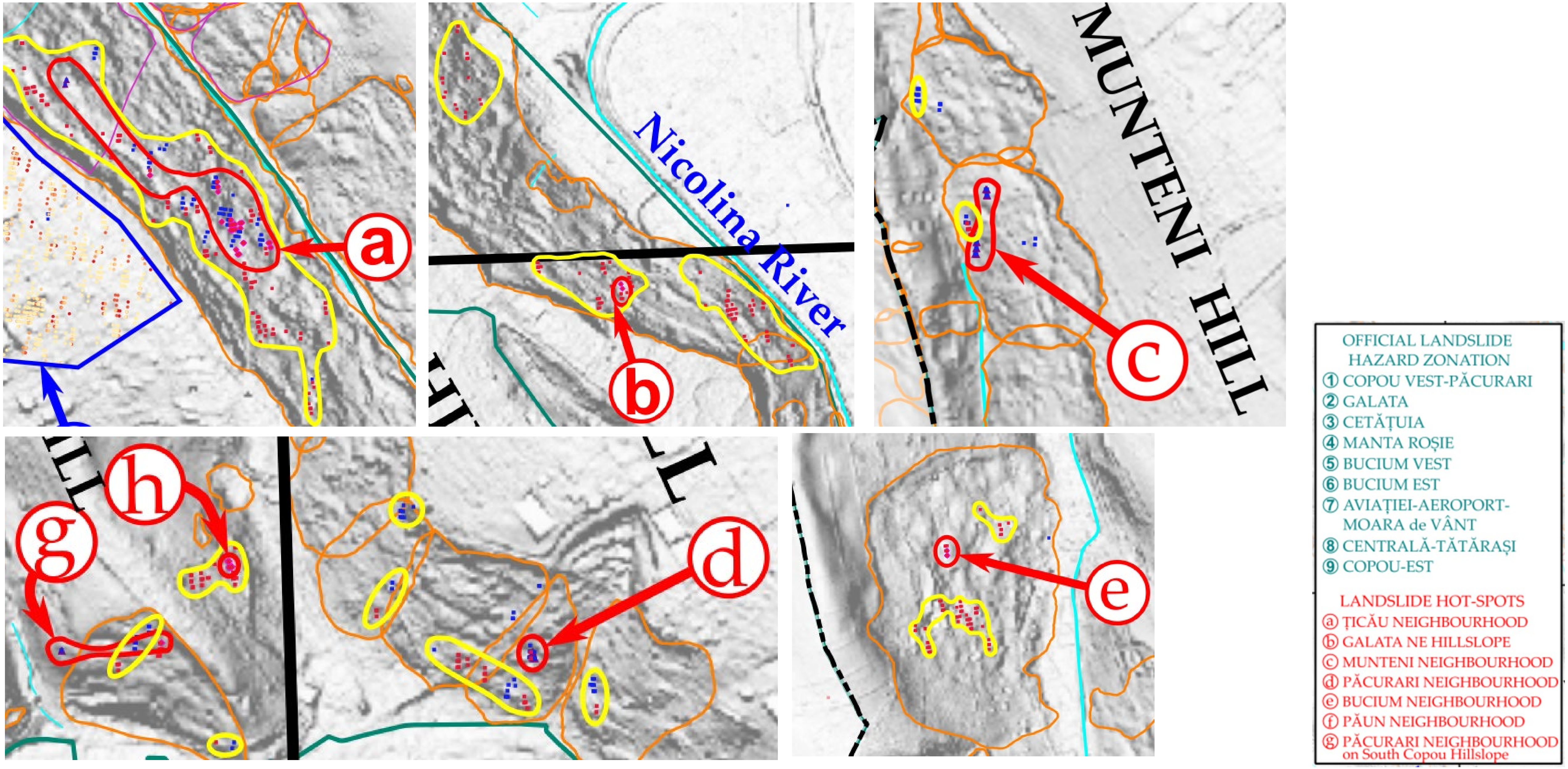
Out of the 9 landslide hazard zones, 7 of them have active displacements related to landslides:

- **Țicău Neighborhood**
- **NE Galata Hillslope**
- **Munteni Neighborhood**
- **Păcurari Neighborhood**
- **Păcurari Neighborhood** (Southern Copou Hillslope)
- **Bucium Neighborhood**
- **Păun Neighborhood**
- **Ciric Sport Base**



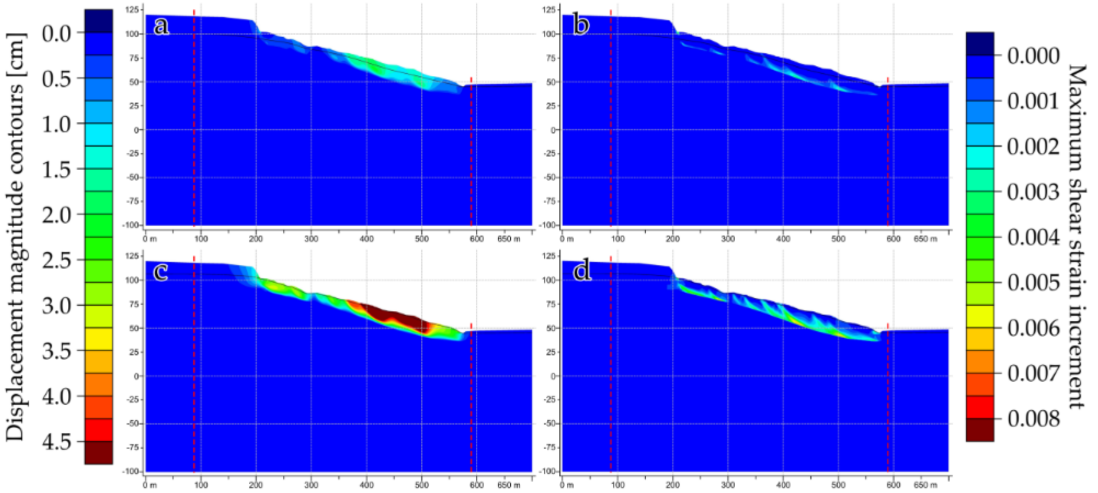
The identified landslide velocity hot-spots based on the Varnes classification thresholds.

SAR results – post-processing and landslide hot-spots zonation

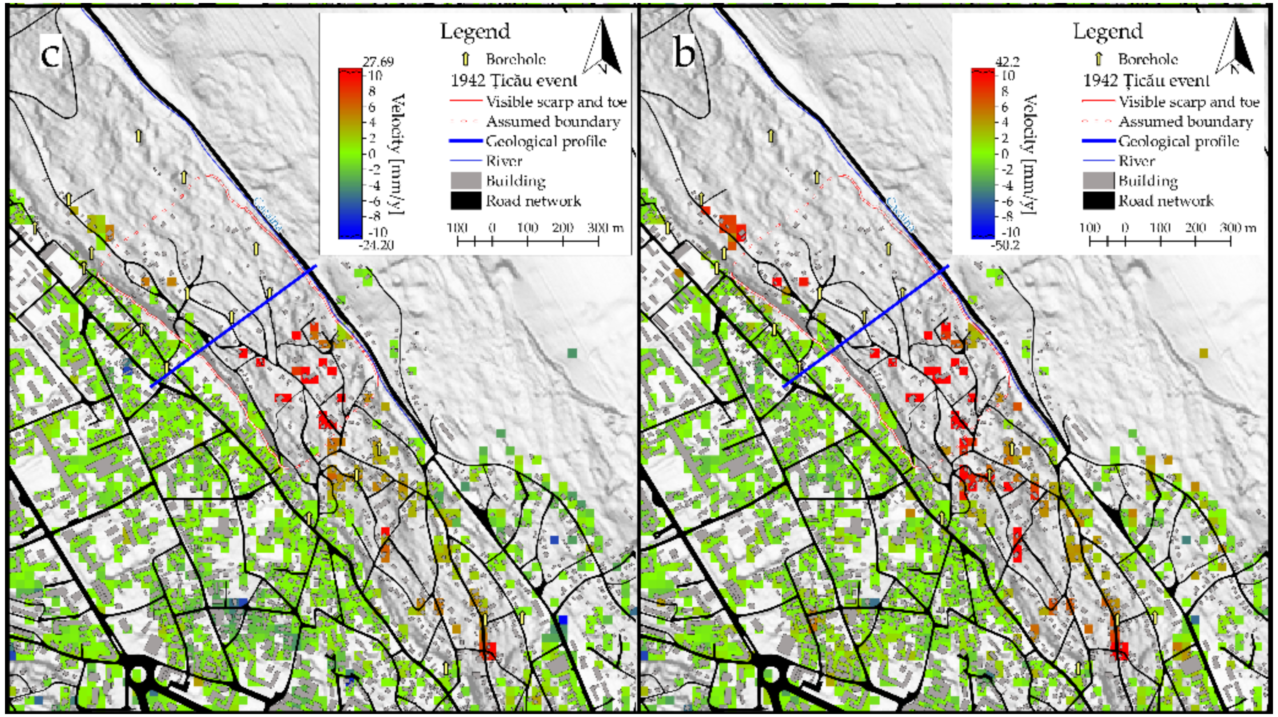


Landslide hot-spots: a) Țicău neighborhood; b) Galata neighborhood; c) Munteni neighborhood; e) Bucium neighborhood; d, g, h) Păcurari neighborhood.

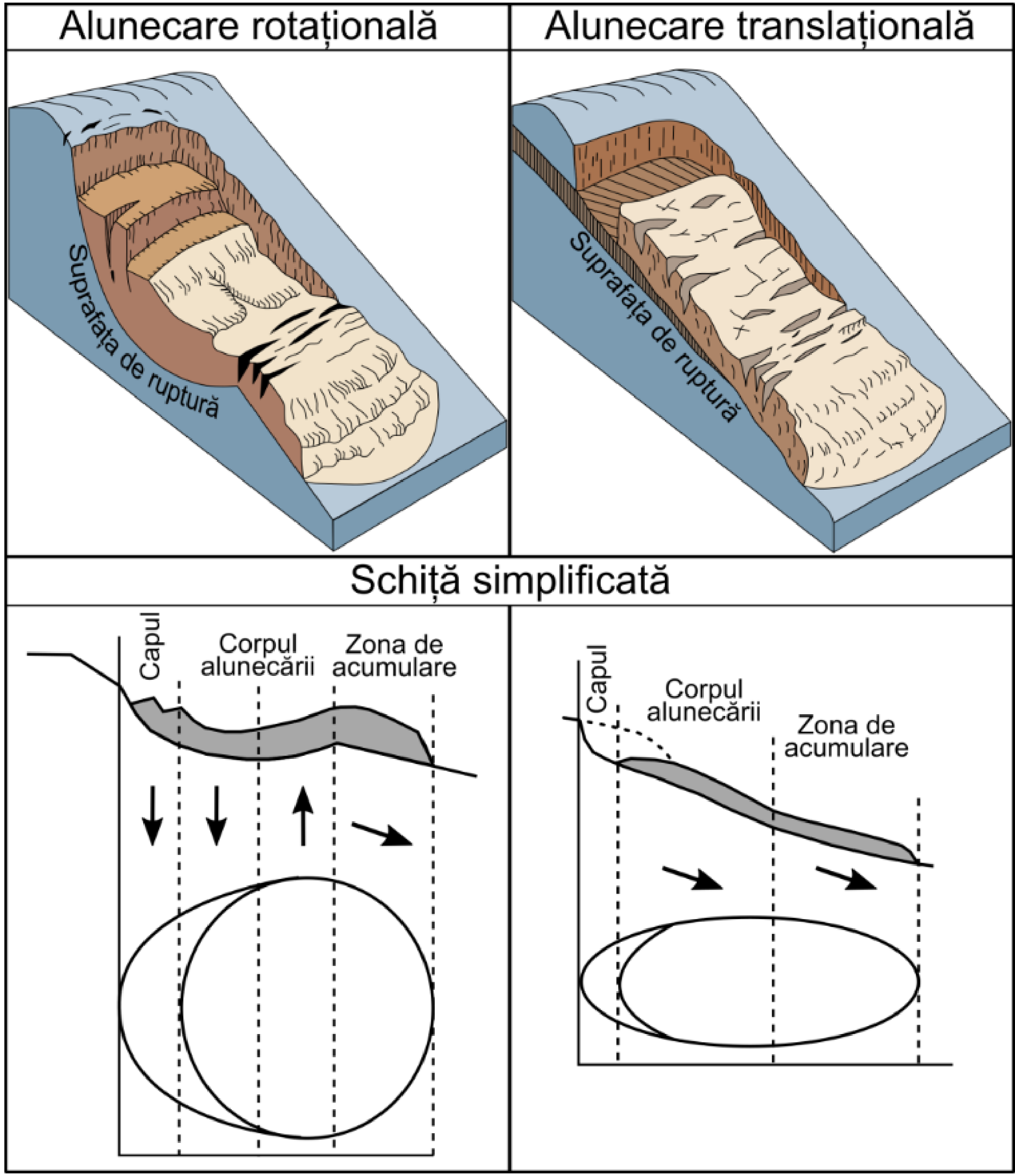
Landslide mechanism



The displacement field and the sliding surface of the Țicău landslide simulated using 2D numerical modeling.



Vertical (a) and horizontal (b) components depicted from the Sentinel-1 results.



Simplified sketch of expected displacements for rotational (left) and translational (right) sliding mechanisms.

Where are in the case of Iași Municipality?

- 1. Restricting development in landslide-prone urban areas, a function assisted by mapping landslide susceptibility;
- 2. Requiring (by means of codes) that grading, excavation, landscaping, construction, vegetation clearance, and drainage activities not contribute to slope instability;
- 3. Protecting existing developments and population by physical mitigation measures, such as slope geometry modifications, drainage, counterfort berms that serve as buttresses, and protective barriers;
- 4. Development and installation of monitoring and warning systems.

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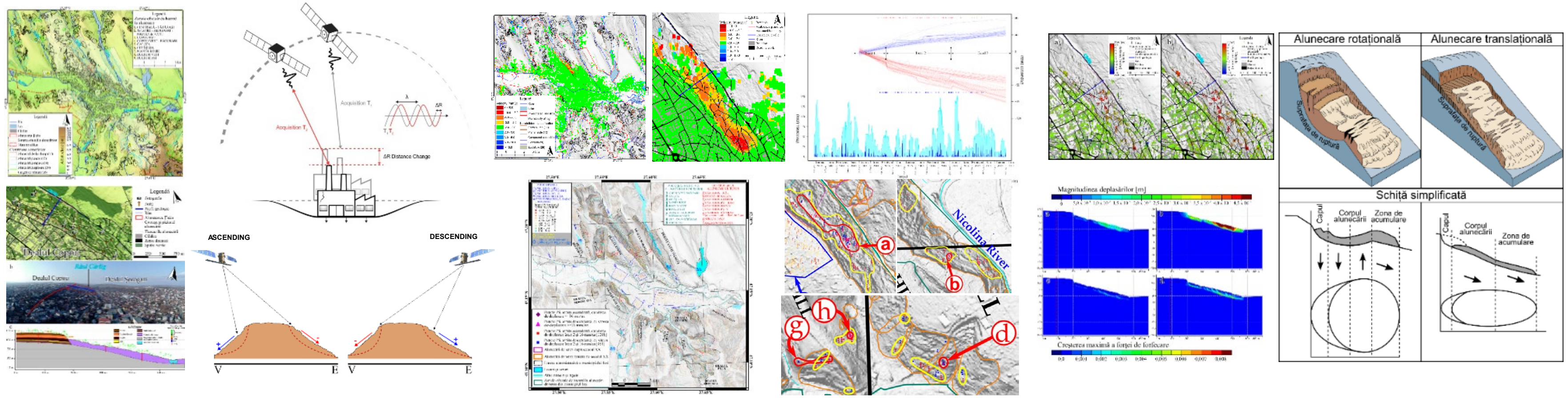
nicusor.necula@uaic.ro

THANK YOU FOR YOUR ATTENTION!



Thank you for your attention!

Questions?

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