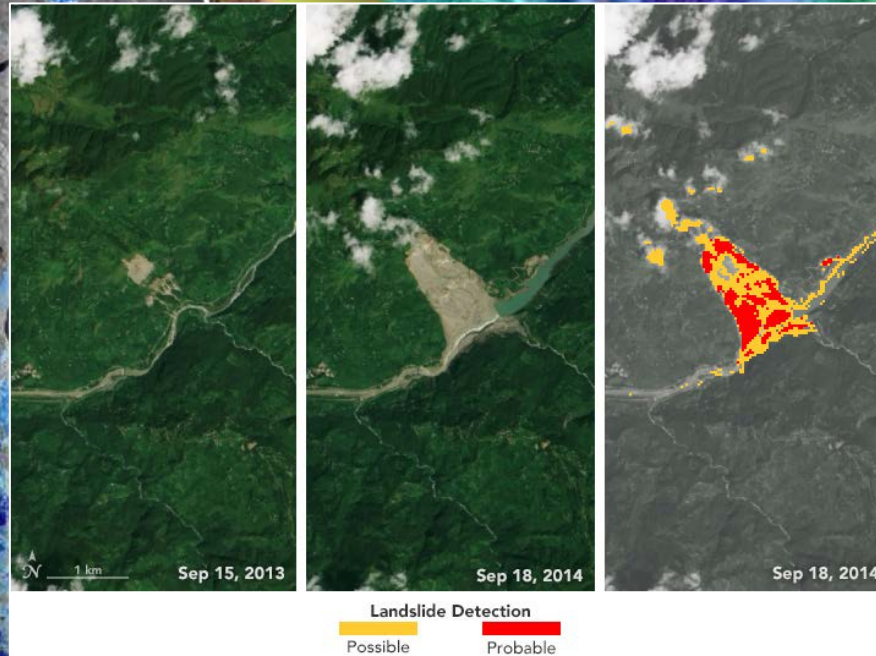


# EO applications for landslide hazard mapping



Jean-Philippe MALET (CNRS-EOST) & Thierry OPPIKOFER (Terranum)

Contact:  
[jeanphilippe.malet@unistra.fr](mailto:jeanphilippe.malet@unistra.fr)  
[thierry.oppikofer@terranum.ch](mailto:thierry.oppikofer@terranum.ch)

28 September 2023

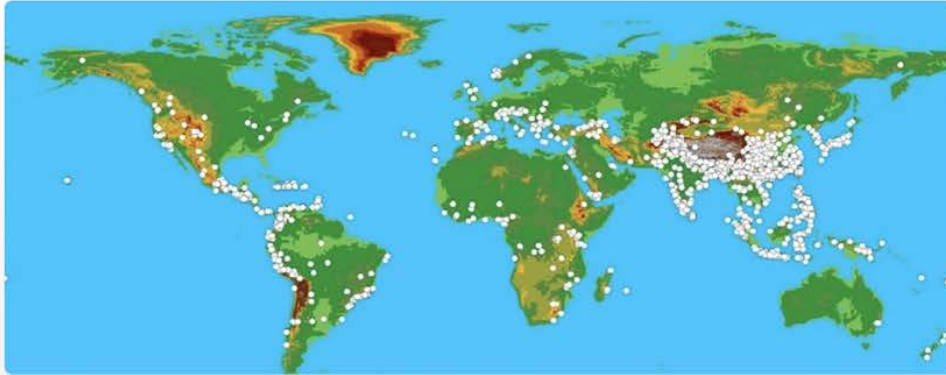


- Introduction to landslide hazard and risk assessment and the use of EO data and services
- ESA initiatives eo4alps-landslides & Digital Twin of the Alps
- Geohazard Exploitation Platform
- EO-based services for landslide studies
- Operational use case #1: InSAR ground-motion maps for landslide monitoring
- Operational use case #2: Forecasting for shallow landslides

- **Landslide: a global phenomenon, observed in multi-hazard environments**

Fatal landslides 2002-2012: ca. 90,000 fatalities

Credits: Petley The landslide blog



- Landslides affect slopes everywhere and cause severe socio-economic constraints in mountainous regions and significant risks to people and infrastructure.

- **Many triggering factors → large diversity of landslide types**

Major triggers



Earthquakes



Hydrometeorologic extremes  
(e.g. typhoon)

New Zealand: 2016 (7.8Mw) ca. 6,000 landslides  
Nepal: 2015 (7.8Mw) ca. 20,000 landslides

Taiwan: 2009 Typhoon Morakot: ca. 20,000 landslides

Nepal:  
Bhote Koshi  
(drone  
image  
1 month  
after EQ)



Credits: K. Cook (GFZ)

Taiwan:  
before and after



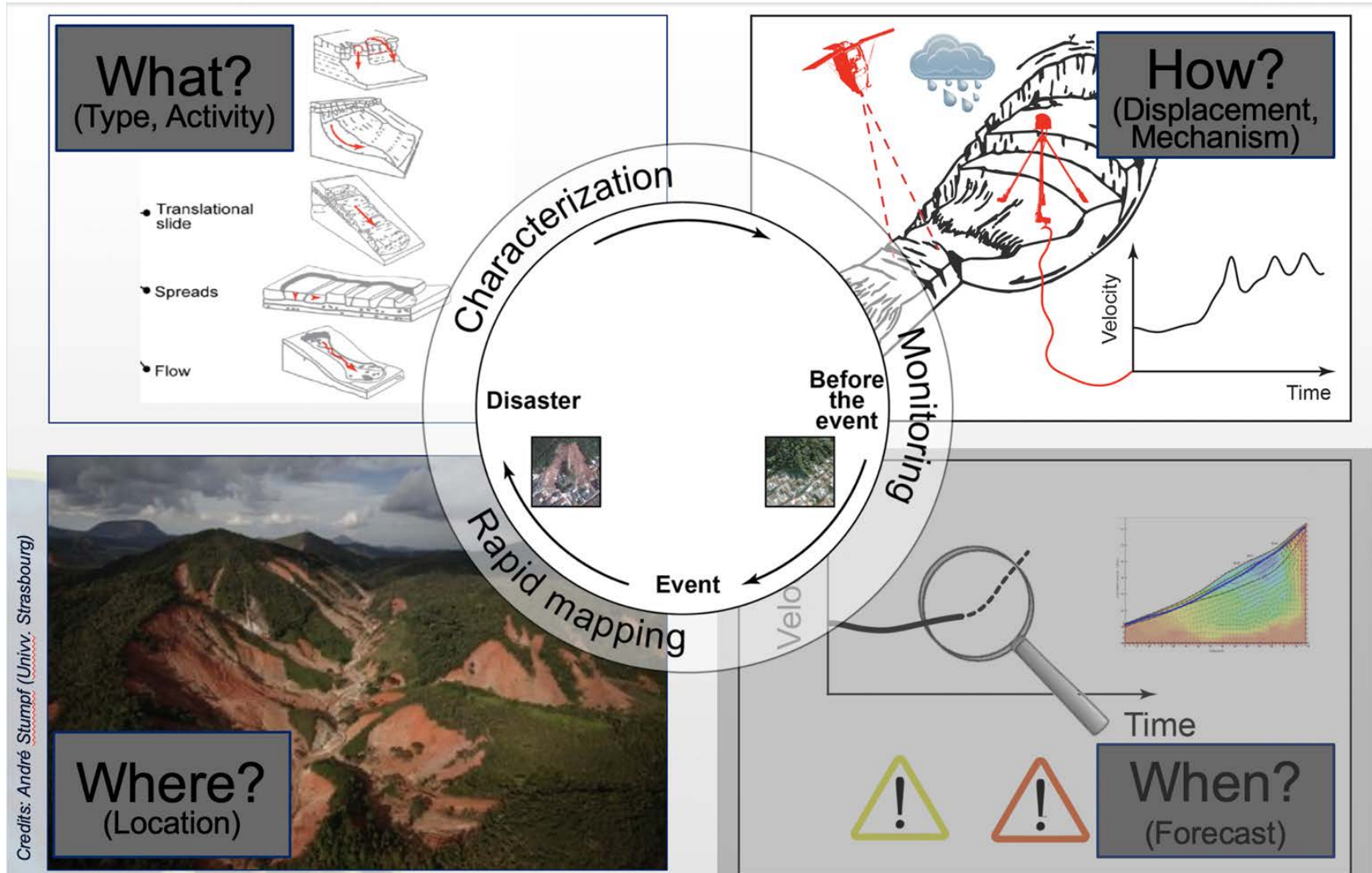
Credits: Tsou Univ. Kyoto

- Variety of landslide types (size, velocity, shape, etc)
- Landslides are difficult to predict and still often to detect



## Key issues for the use of EO data for landslide analyses:

- Which EO data?
- Which processing technique?
- *For which application?*
- *For which landslide type?*
- *For which landscape?*



# ESA initiative: the eo4alps-landslides App on the GEP



- ESA funded an initiative to streamline the access to satellite Earth Observation (EO) data and their use in services for landslide risk management in the Alps
- Operational services at different scales of analysis (region, municipality, specific landslide) with a progressive level of detail
- Two categories of services
  - Services accessible on the Geohazards Exploitation Platform (GEP) and all actions (image search, processing, visualization, export of the results) are carried out online
  - Highly tailored services and processing accessible by request to the third-parties owning the services
- User-oriented services with the participation of over 70 authorities and stakeholders responsible for landslide risk management



TERRA)UE

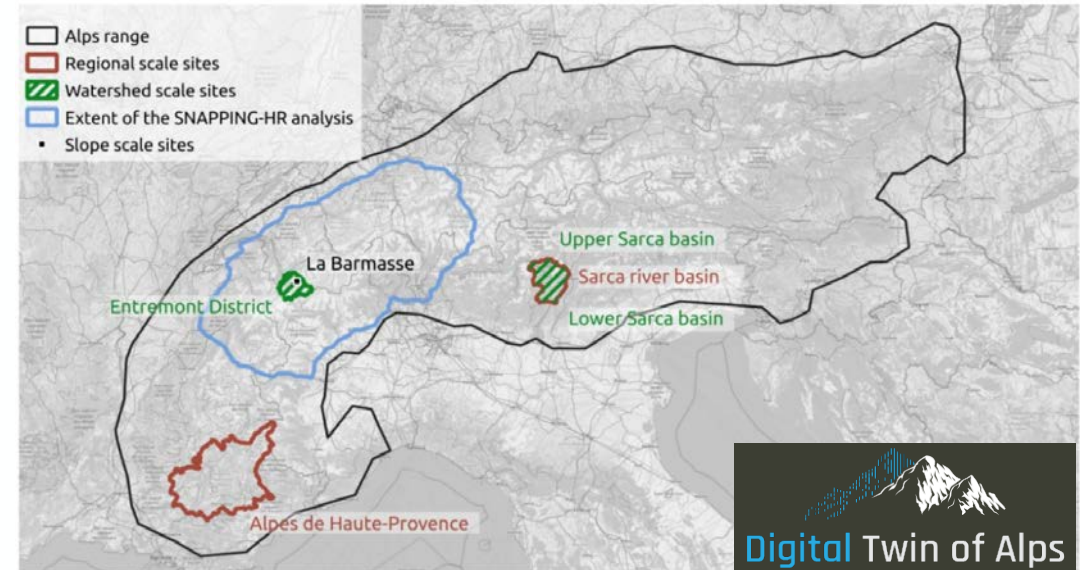




# ESA initiative Digital Twin of the Alps



- A Digital Twin is a digital reproduction of a system existing in the real world
- ESA funded DTA initiative aims demonstrating the potential of up-to-date EO data and processing algorithms to represent natural processes in the Alps
- Disaster Risk Management:
  - Landslides hazard and risk
  - Flood modelling
- Water Resources Management
  - River discharge monitoring
  - Snow monitoring and modelling
  - Soil moisture and droughts monitoring and modelling
  - Extreme event forecast
- Combination of EO data, physical models and in-situ measurements for a most realistic digital representation of the alpine region



# Geohazard Exploitation Platform



- The Geohazard Exploitation Platform (GEP) is an online platform supporting the exploitation and practical use of satellite EO data (optical imagery, SAR) for geohazards
- GEP provides on-demand and systematic processing services and cloud-computing resources



The screenshot displays the geohazards platform interface. On the left, a search results panel shows a list of satellite observations for the 'eo4alps-landslides' project, including details like 'S2A SZMS1C INSNOBS Level-1C 108 Wed, 06 Sep 2023 19:26:01 GMT'. The main area is a map of the Alps region, showing topographic features and a search bar. On the right, a 'Processing Services' panel lists various services such as ALADIM-HR, ALADIM-VHR, DSM-OPT, FASTVEL, SNAPPING IFC, SNAPPING PSI, and TimeSAT. A small inset window in the bottom right corner provides information about the 'eo4alps-landslides' project, stating it was launched by the European Space Agency (ESA) to exploit satellite data for mapping, monitoring, and modeling natural hazards in the Alpine region.

[geohazards-tep.eu](http://geohazards-tep.eu)



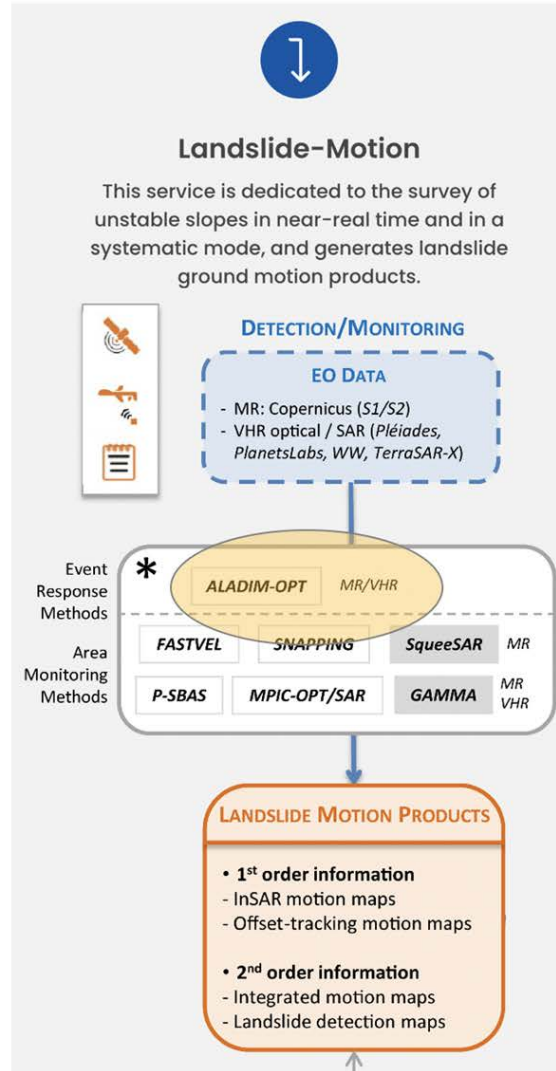


## Services for landslide detection and mapping

Usefulness:

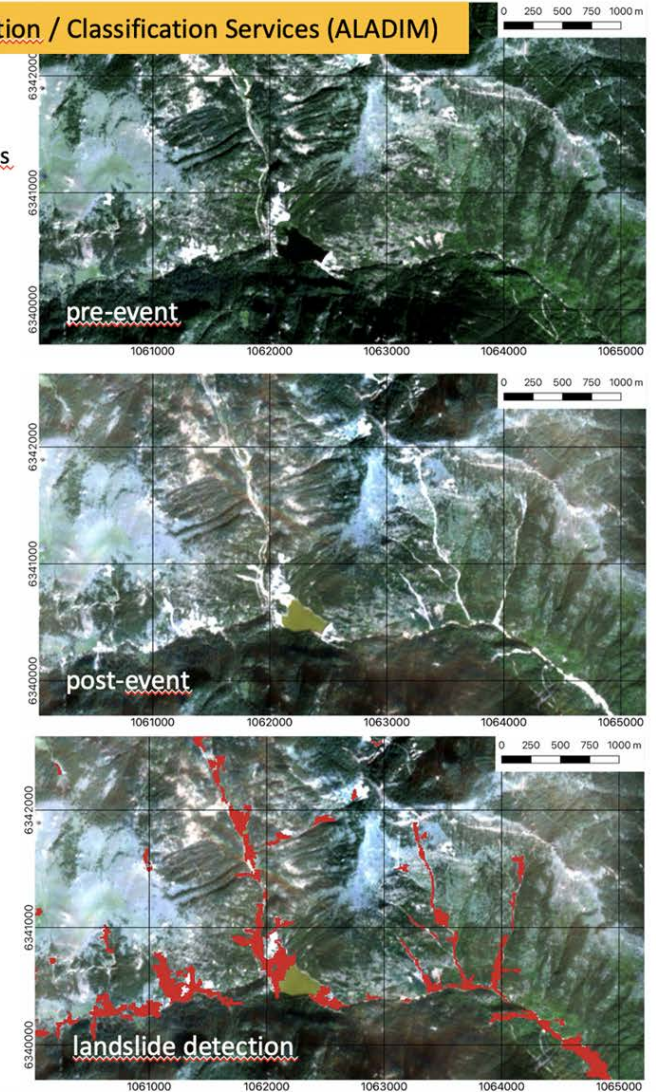
- rapid mapping - crisis management
- update of landslide inventories

## ALADIM service on GEP



## Change Detection / Classification Services (ALADIM)

Alex storm, Oct. 2020  
South French Alps



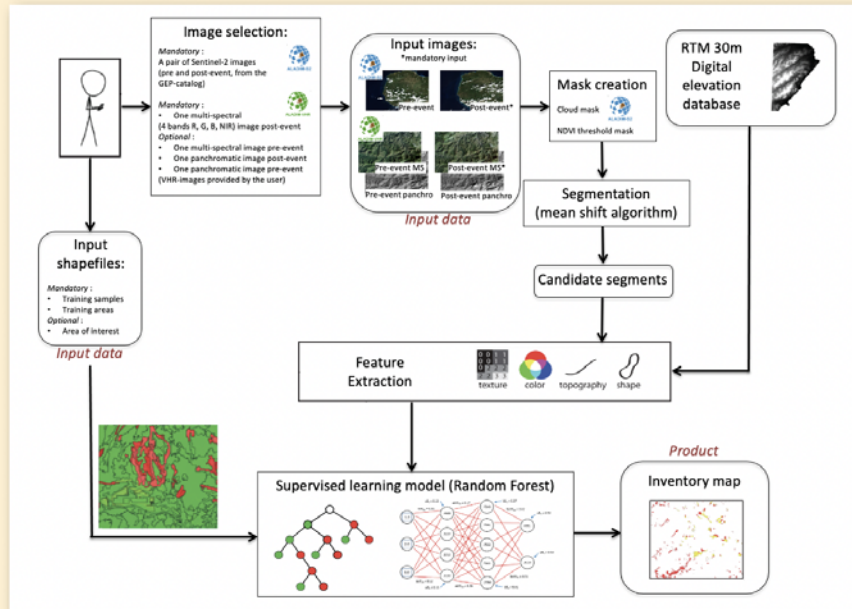


## PROCESSING CHAIN



The processing chain includes:

- A **segmentation** step, optimized in terms of accuracy and computing time whatever the input data spatial resolution
- A **feature extraction** step, consisting in feature computation (spectral, textural, topographic, morphometric)
- A **per segment classification** step, based on a random-forest classifier trained by a sample of landslide manually digitalized

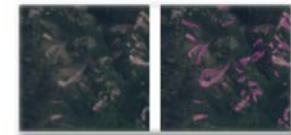


## WEB-SERVICE ON GEP



- From a **data perspective**, the free access to the **Sentinel-2** and **Landsat-8** missions offers opportunities for the design of an operational service of landslide inventory mapping at any time and everywhere on the Earth.
- From a **processing perspective**, the Geohazards Exploitation Platform –**GEP**– of the European Space Agency –**ESA**– allows the access to processing algorithms in a high computing performance environment.
- From a **community perspective**, the Committee on Earth Observation Satellites (**CEOS**) has targeted the take-off of such service as a main objective for the landslide and risk community.

1. Manual creation of a landslide training sample



2. Selection of input data and parameter setting

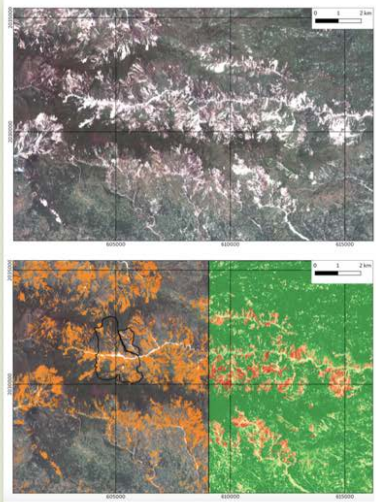
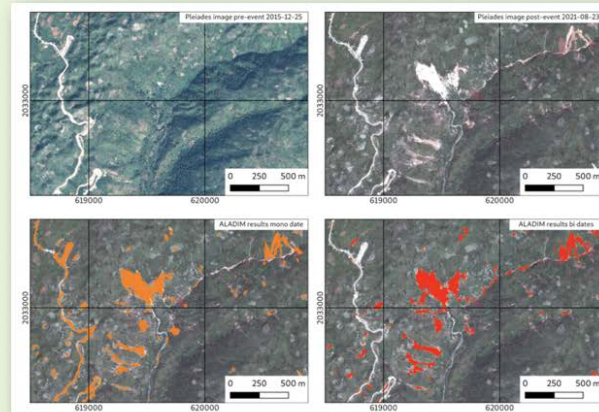




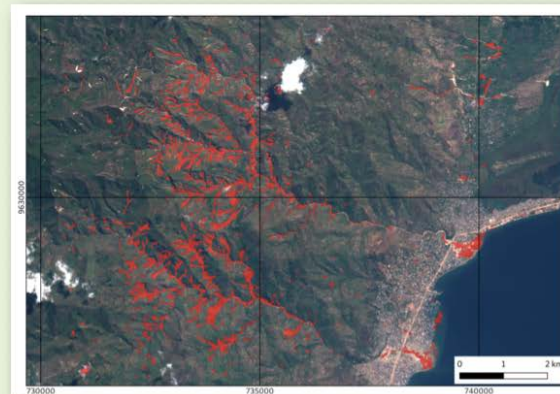
## RESULTS

Landslide inventory maps generated using:

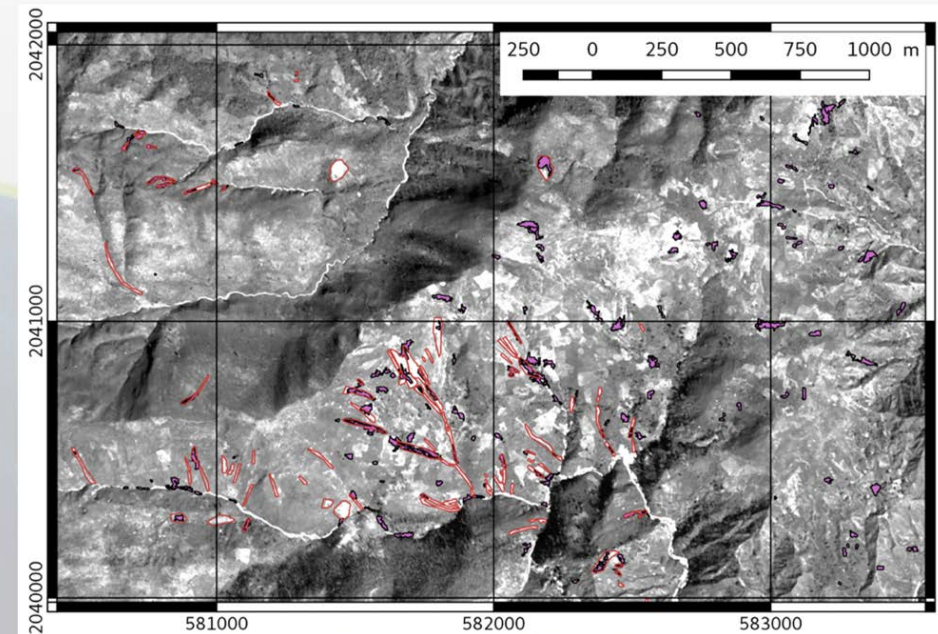
- Pléiades imagery over Haiti impacted by earthquake & heavy rains in 08-2021



- Sentinel-2 imagery over Uvira region (DRC) impacted by torrential rains in 04-2020



## ALADIM mapped landslides in Haiti from Hurricane Matthew



Aline Déprez & Jean-Philippe Malet (CNRS/EOST)

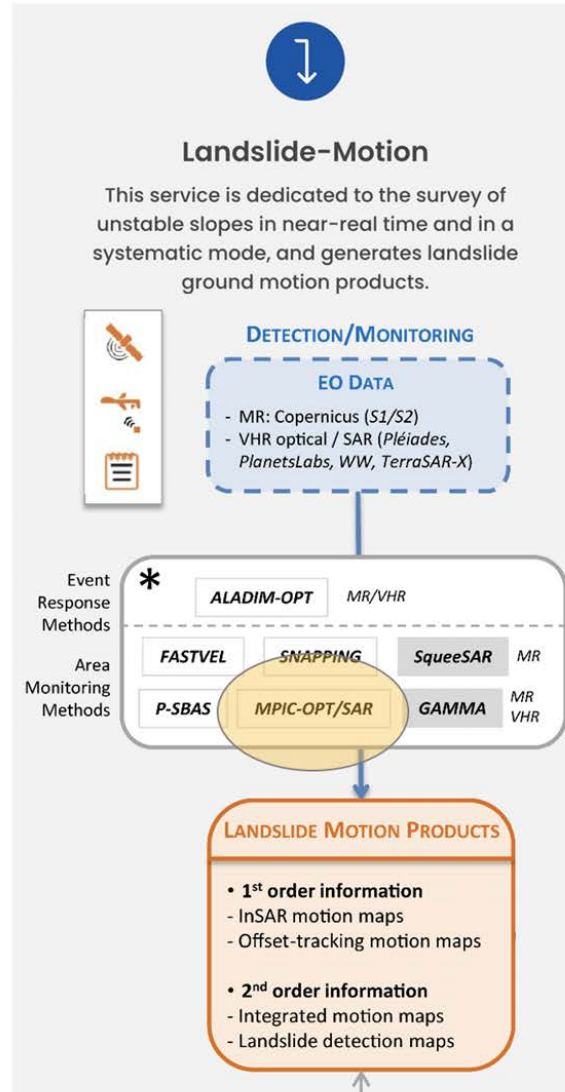


## Services for landslide monitoring survey - OPTICAL data

Usefulness:

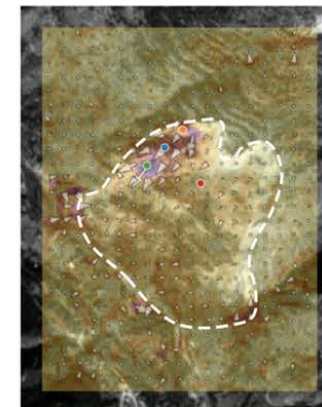
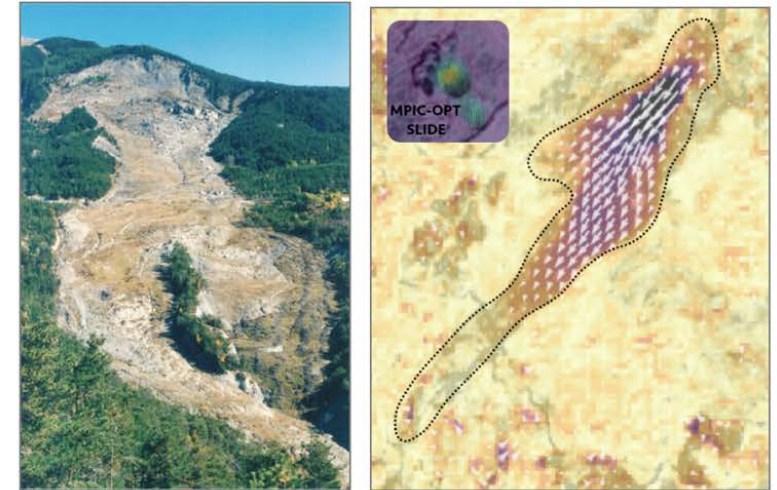
- landslide deformation analysis
- landslide forecasting

## GDM-OPT service on GEP

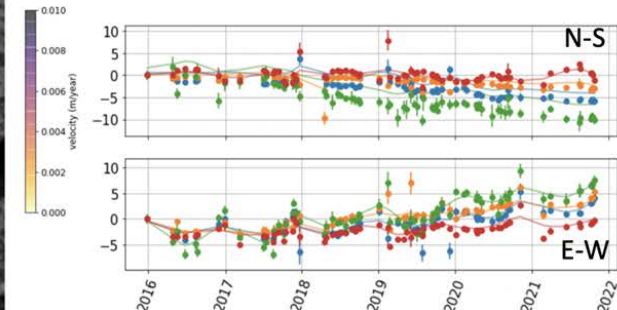


## Ground Motion Services / MPIC-OPT-SLIDE – Optical Image Correlation

La Valette landslide, French Alps  
Time series of Sentinel-2 image  
2015 – 2020



La Clapière landslide, French Alps  
Time series of Sentinel-2 image  
2016 – 2022



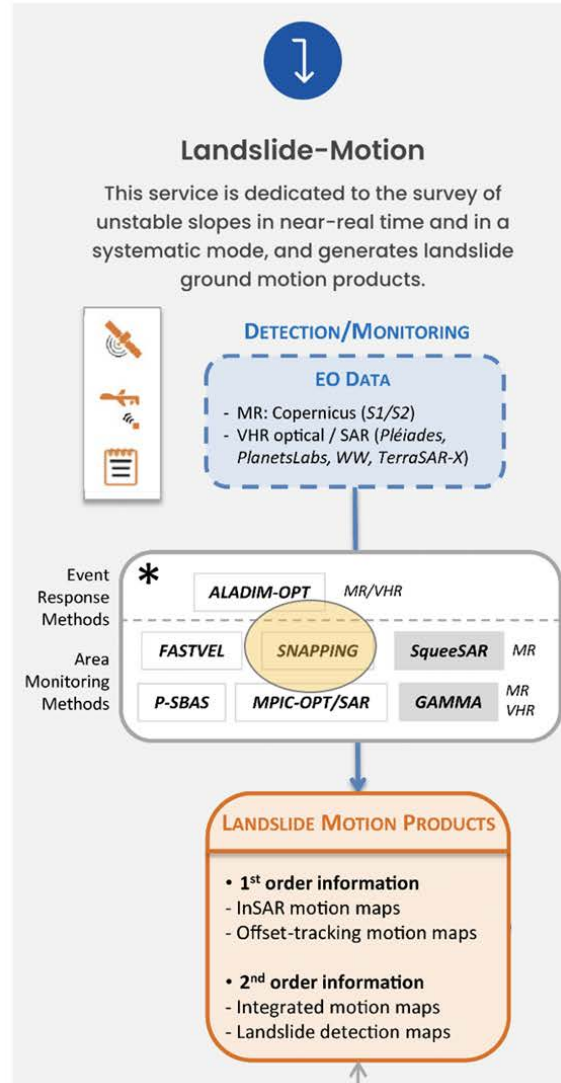


## Services for landslide monitoring survey - SAR/InSAR data

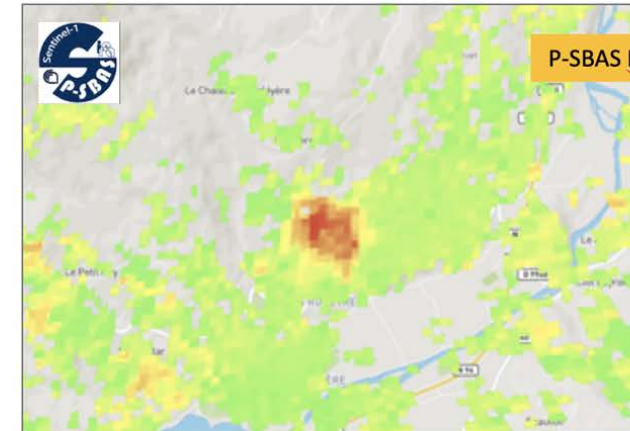
Usefulness:

- landslide deformation analysis
- landslide inventory

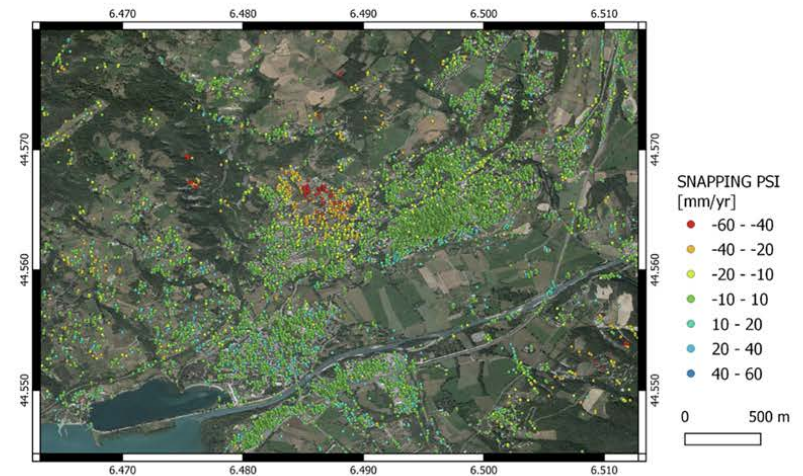
## SNAPPING service on GEP



## Ground Motion Services / SNAPPING MR/HR - PS-InSAR



Hautes-Alpes landslide, Sentinel 1 / 2015-2020





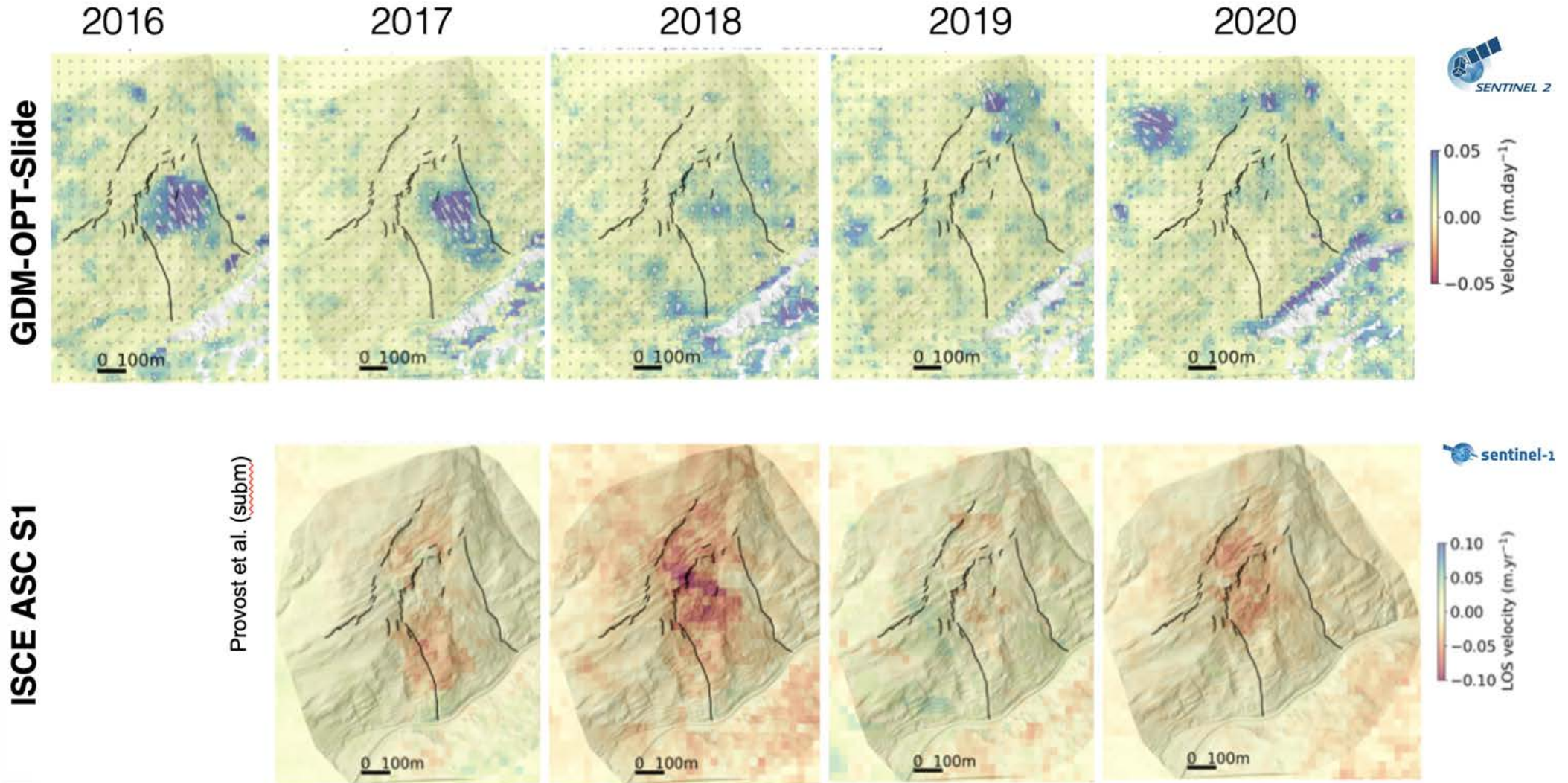
# EO-based services for landslide studies



GDM-OPT +  
InSAR

Revealing  
complex  
landslide  
deformation  
patterns

Aiguilles  
(France)



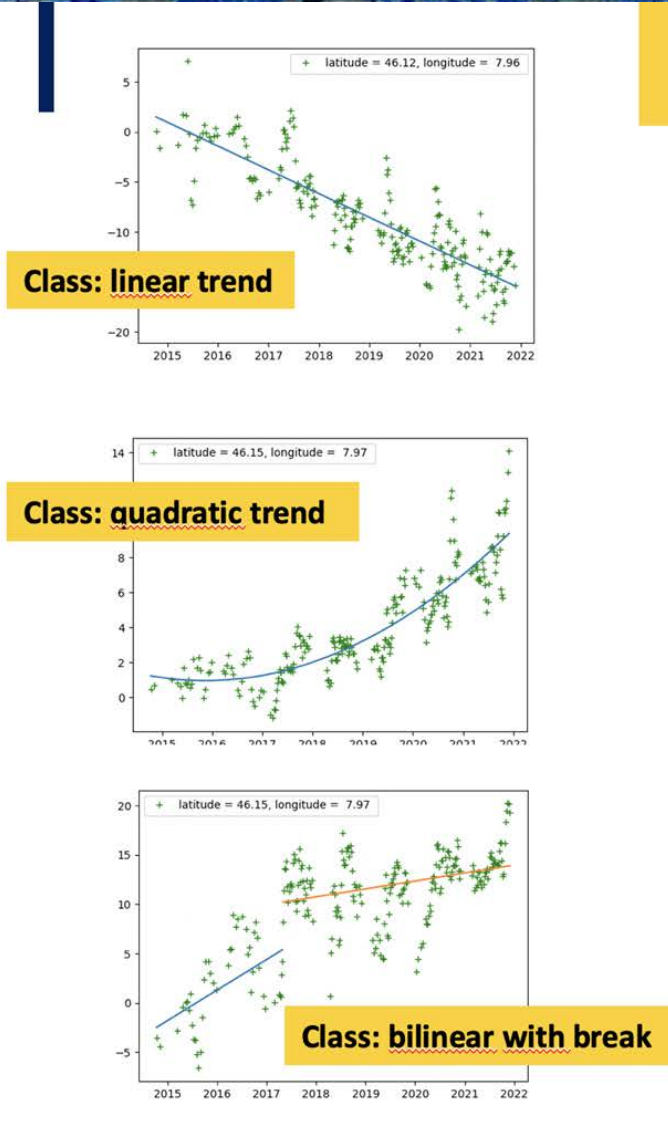


# EO-based services for landslide studies

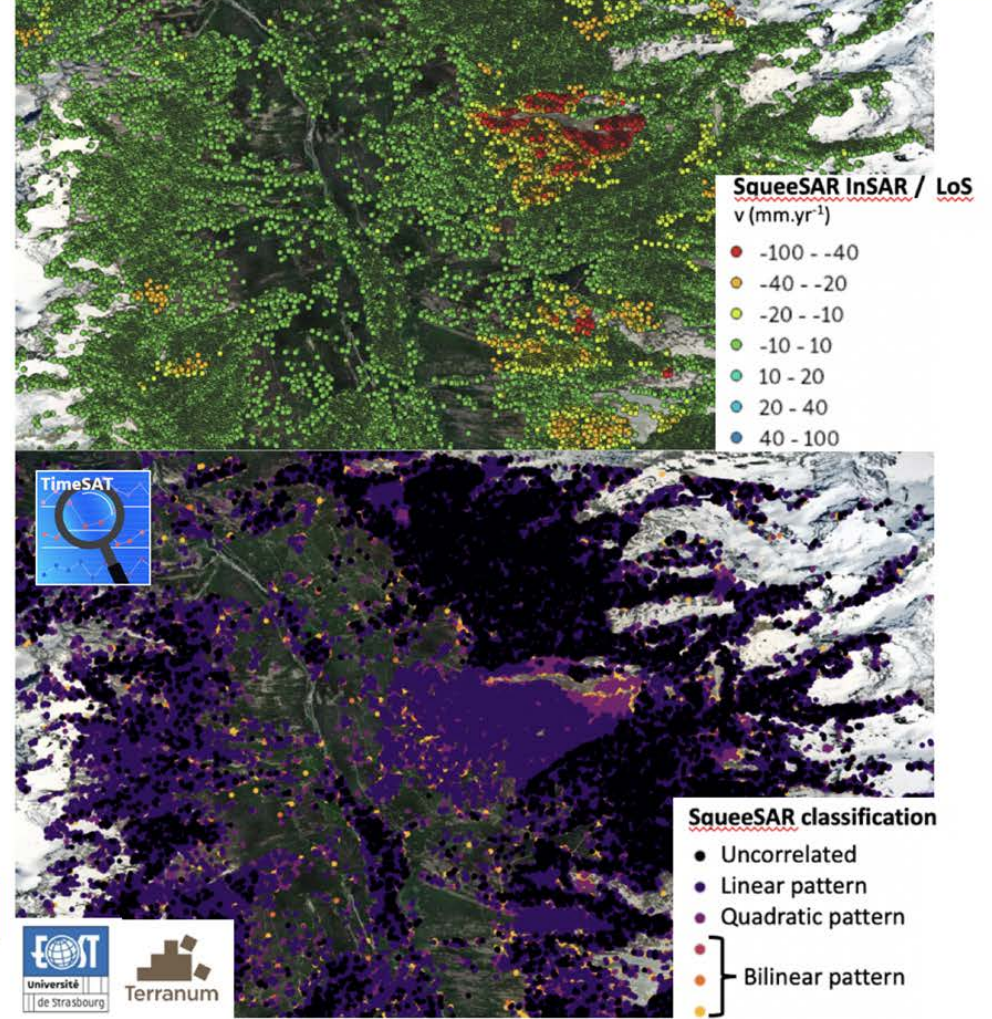


Extracting landslide information from massive EO

TimeSAT service on GEP



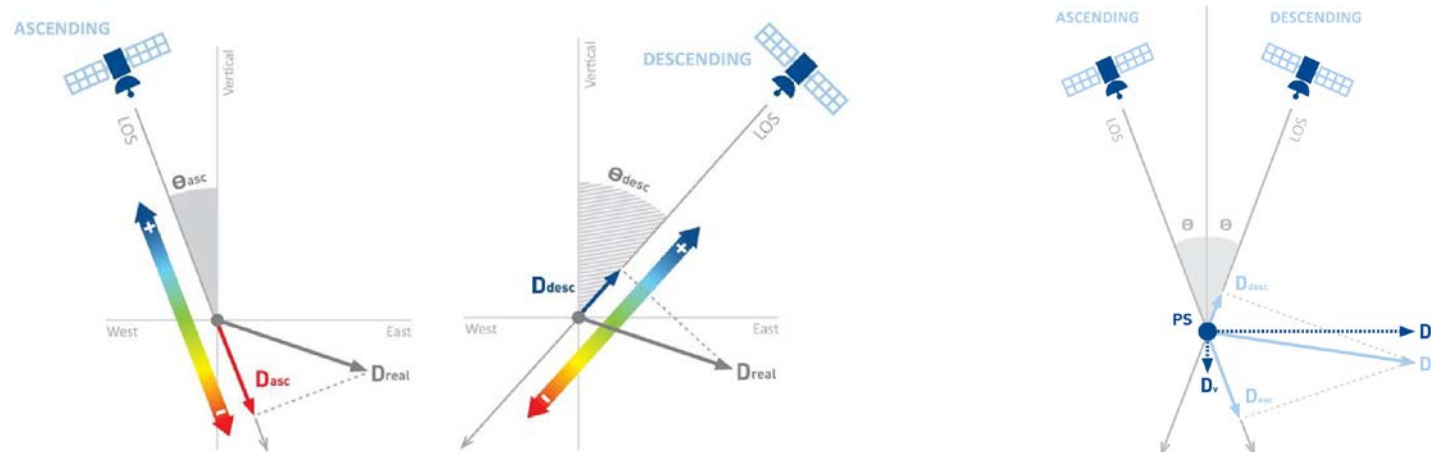
**Post-processing : from EO products to landslide information**  
 from advanced ground motion services (e.g. SNAPPING, SqueeSAR, GDM-OPT) to landslide signals (supervised,/unsupervised classification,+ clustering)





# Operational use case#1: InSAR ground-motion maps

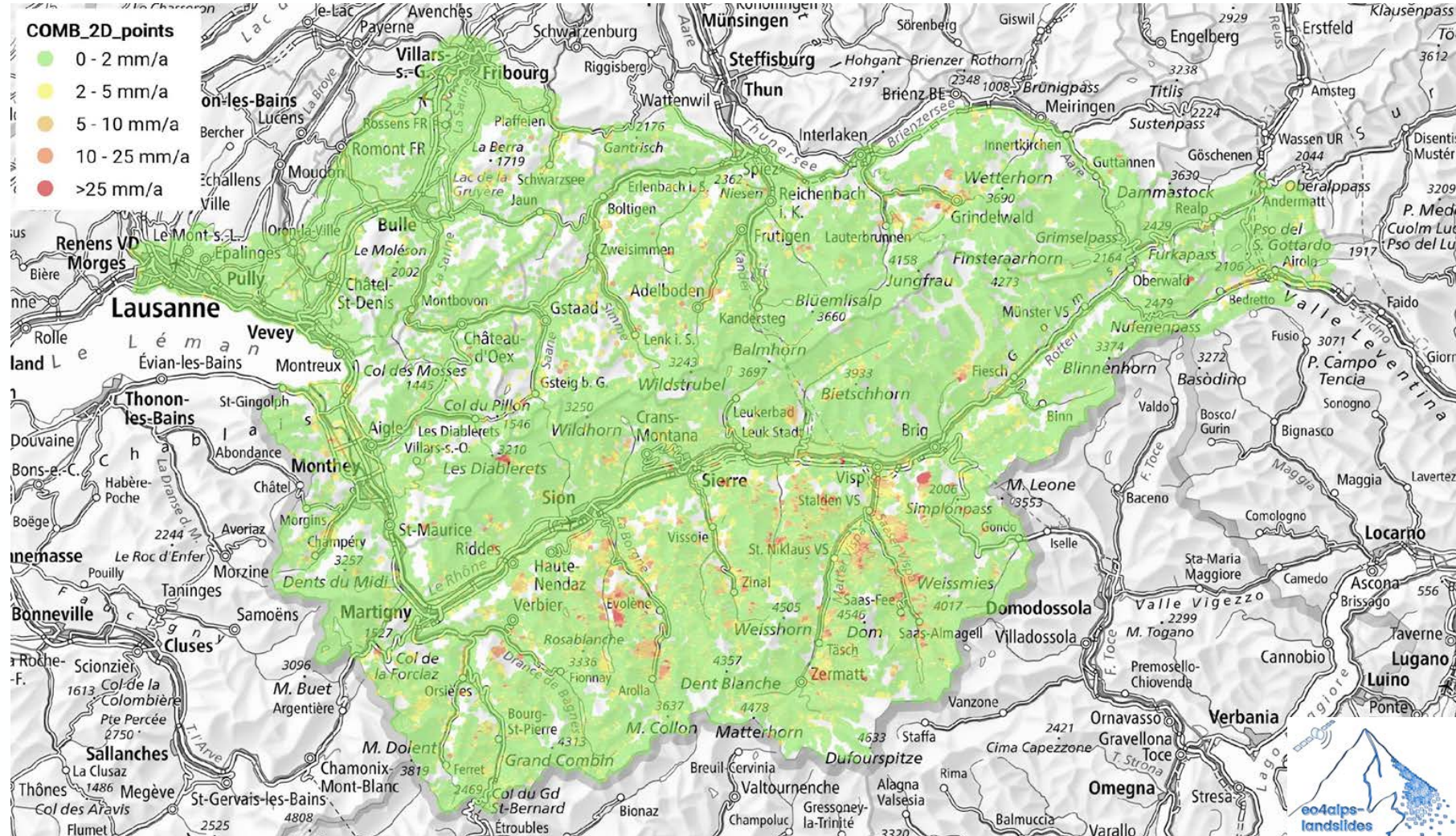
- InSAR ground-motion maps using Sentinel 1 data → can be generated using EO services on the GEP
- Within the framework of the eo4alps-landslides initiative, a tailored SqueeSAR<sup>®</sup> dataset was generated by TRE-Altamira for parts of the Italian, French and Swiss Alps
- SqueeSAR<sup>®</sup> is an advanced InSAR algorithm that combines permanent scatterers (PS) and distributed scatterers (DS) → increases the number of measurement points on natural terrain
- Combination of line-of-sight measurements in ascending and descending orbits to extract the vertical and East-West components of the real displacement vector





# Application 1: InSAR ground-motion maps

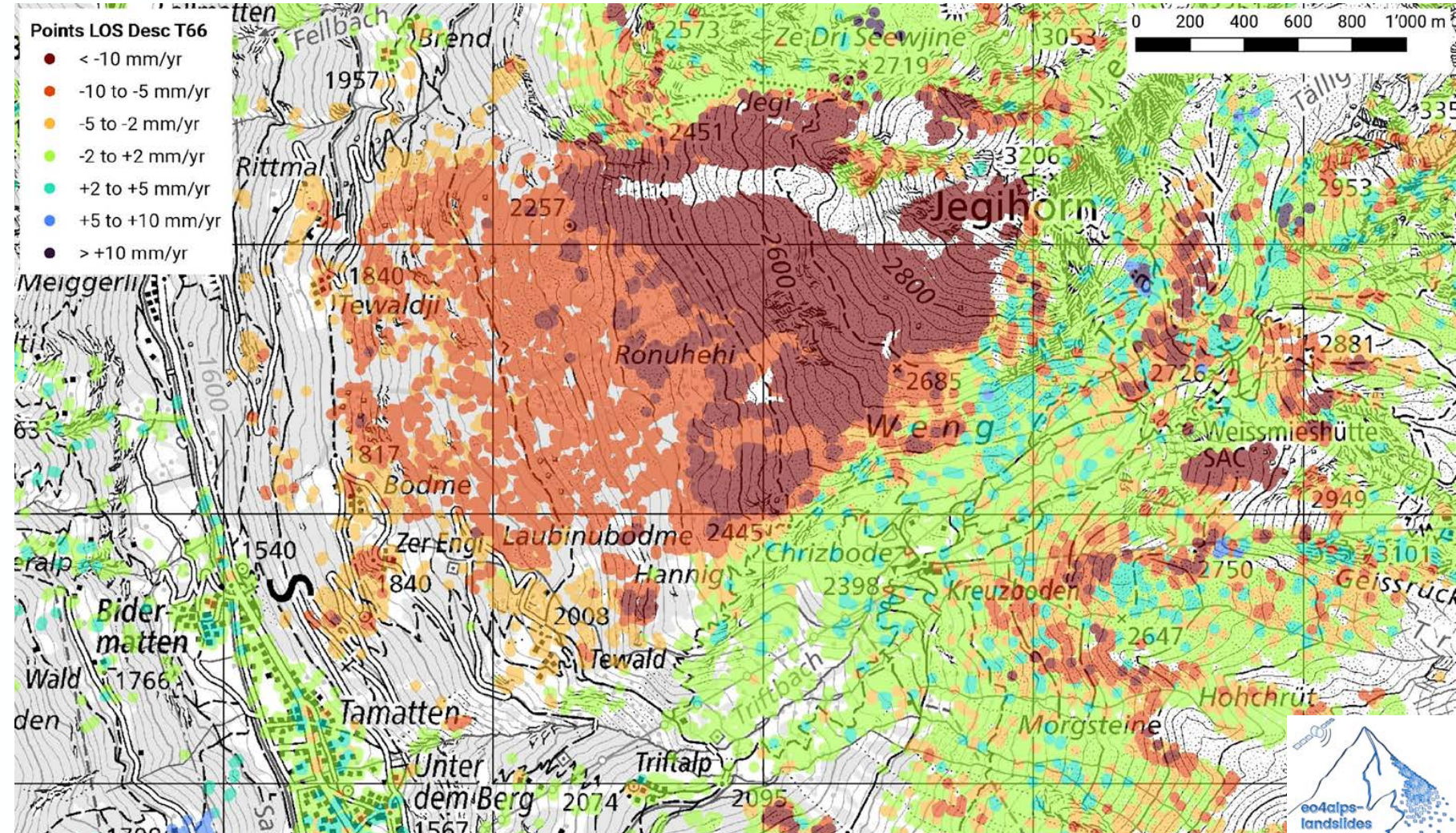
- Average displacement rates in SW Switzerland measured by InSAR
- Several landslide hotspots stand out:
  - Lateral valleys south of the Rhone river (Saas Valley, Matter Valley, Hérémence Valley)
  - Local landslide sites (e.g. Diablerets, Anzère, Moosfluh, Grindelwald, Pointe des Savolaires)





# Operational use case#1: InSAR ground-motion maps

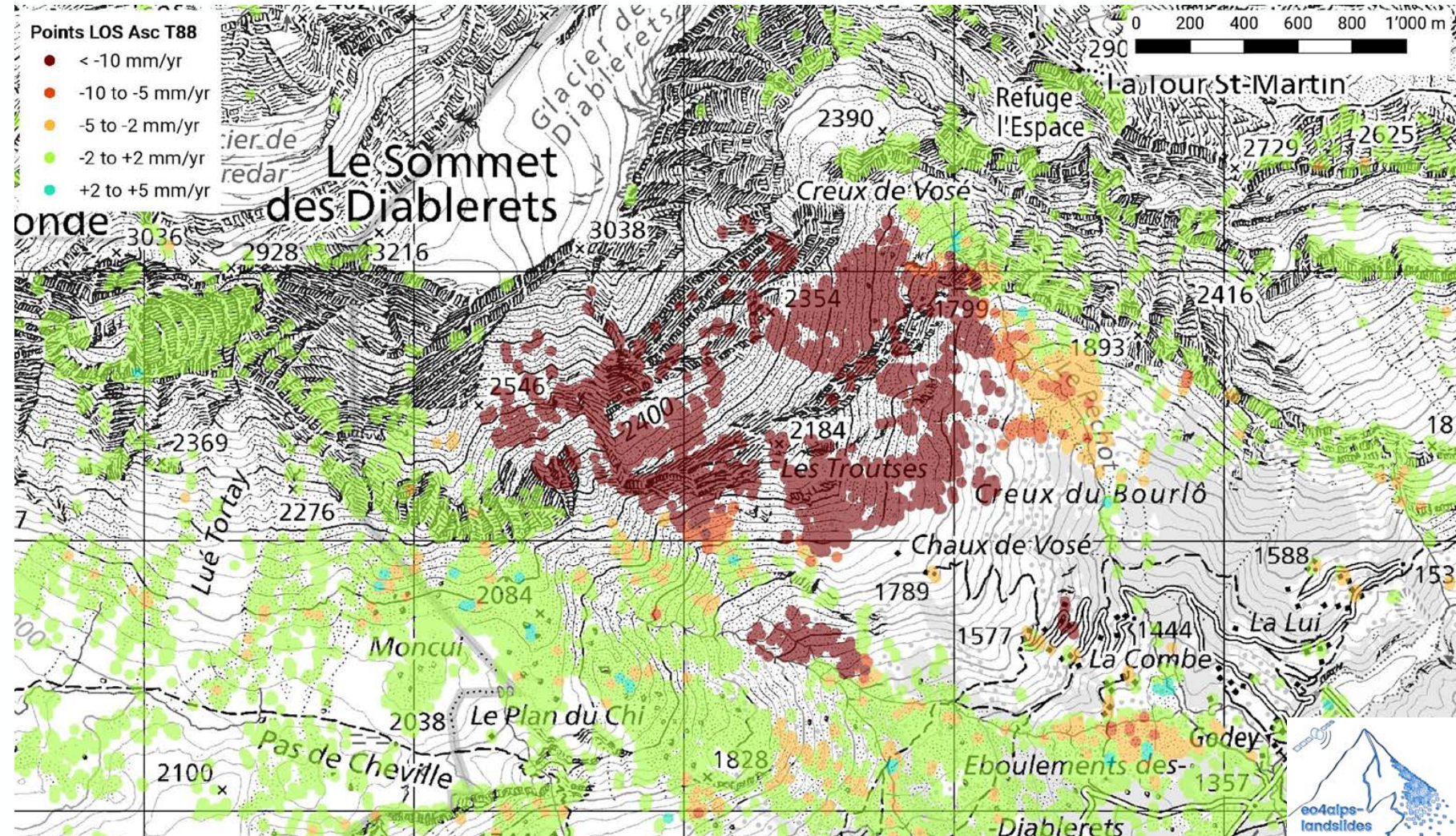
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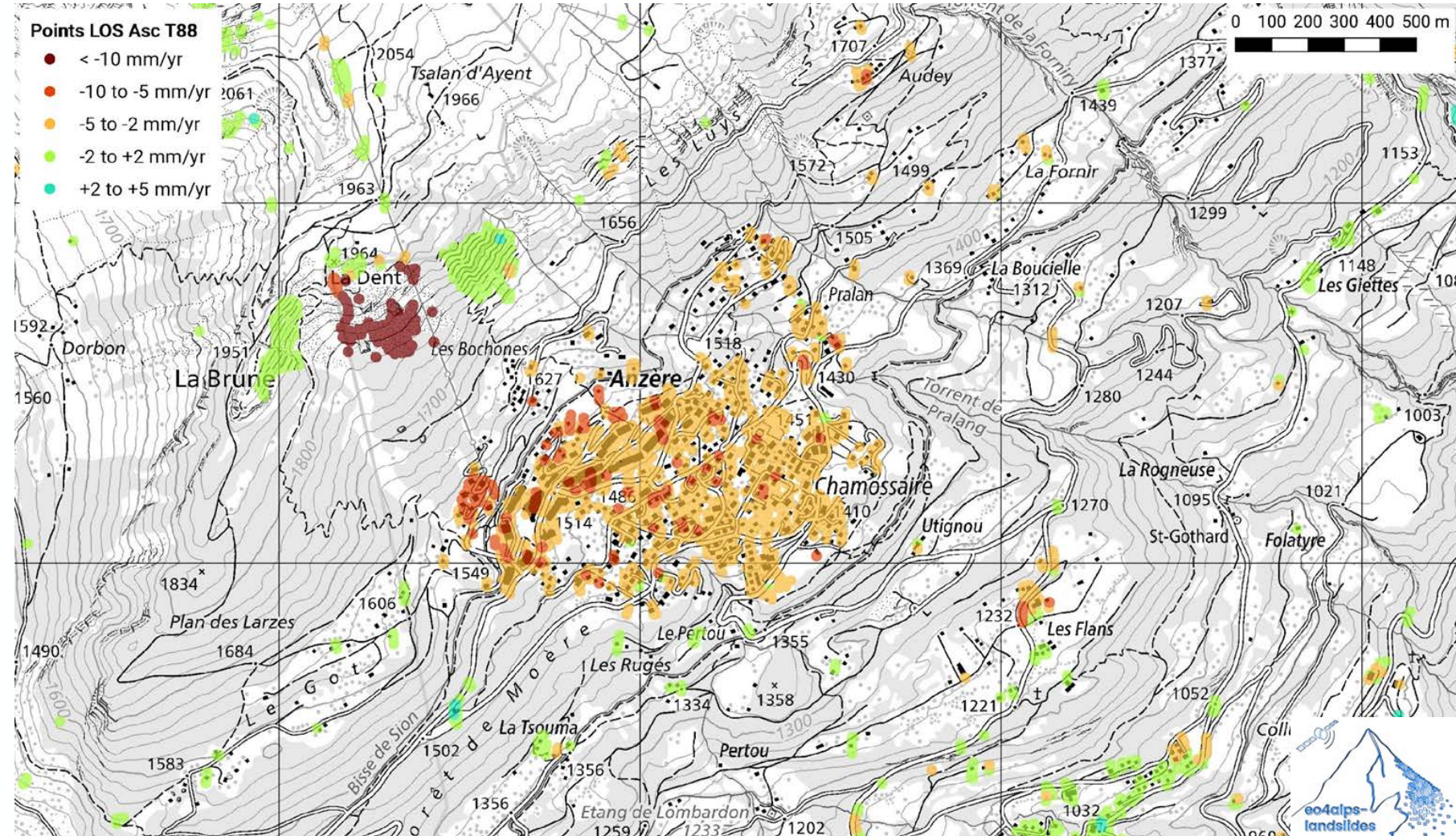
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# Operational use case#1: InSAR ground-motion maps

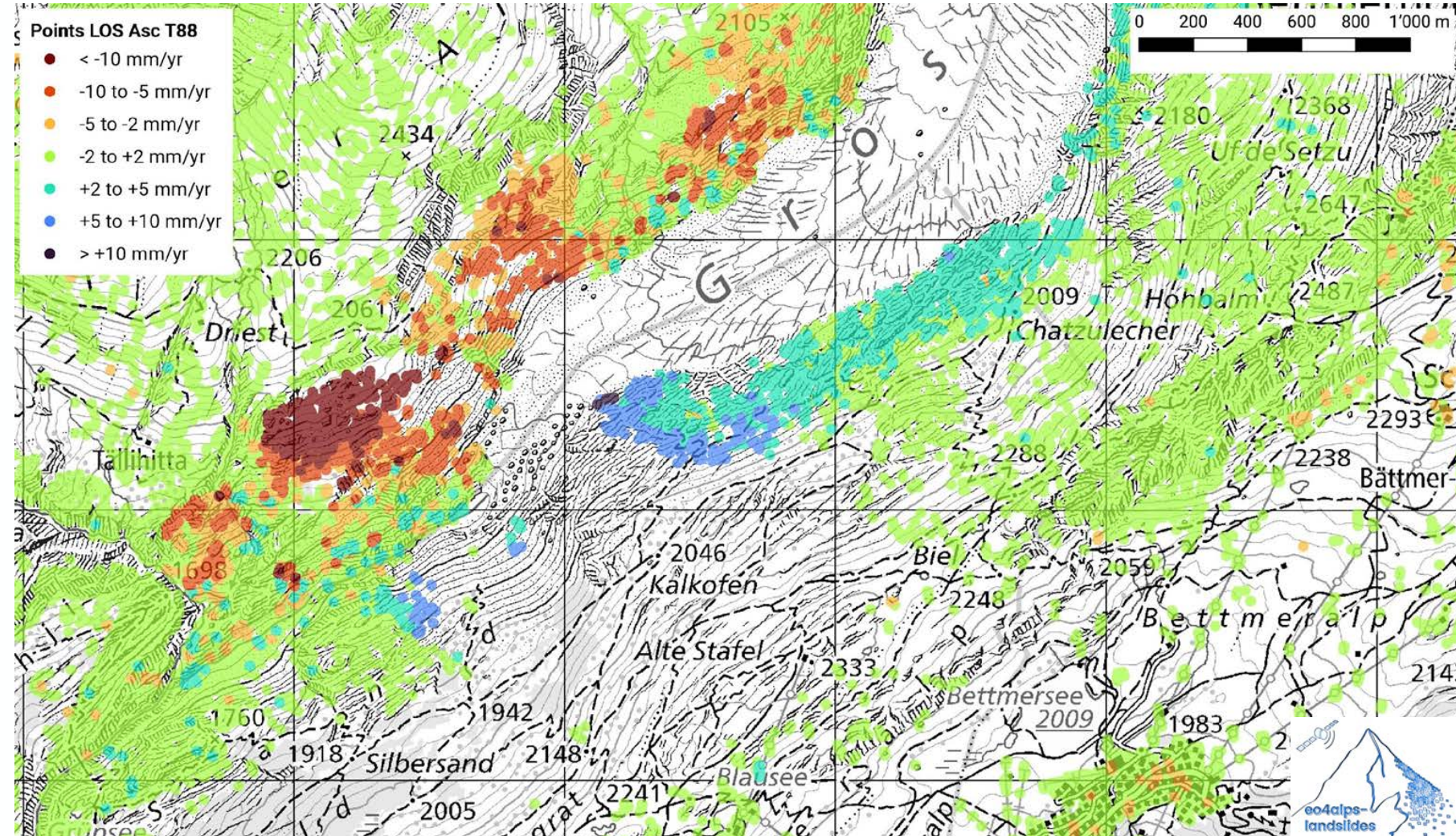
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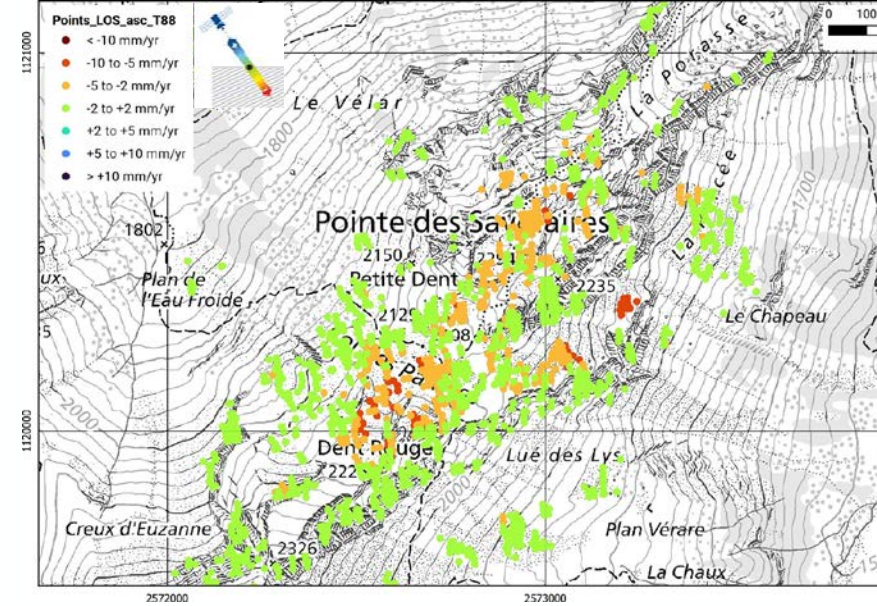
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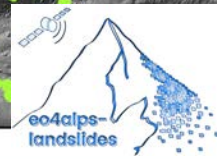
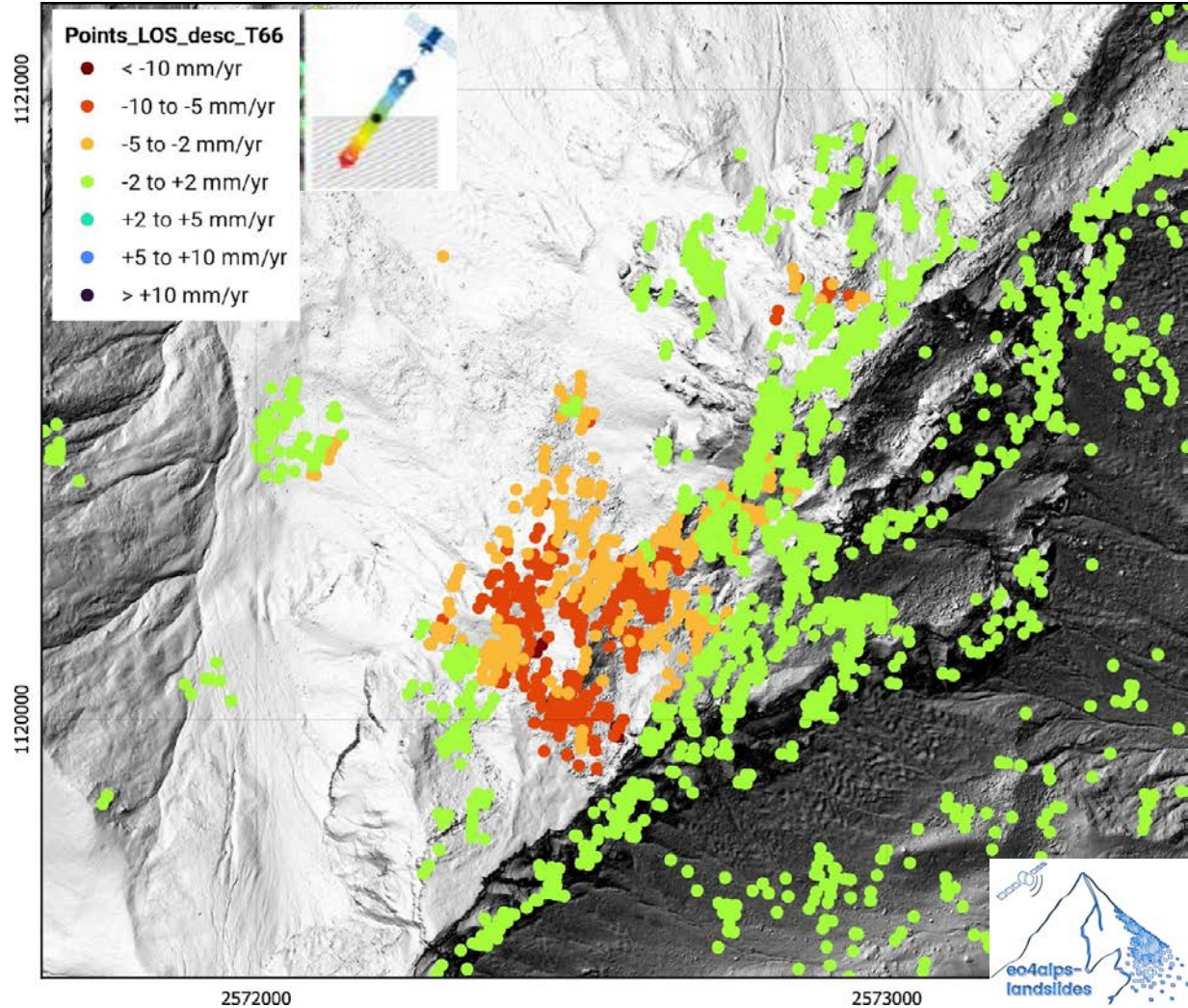
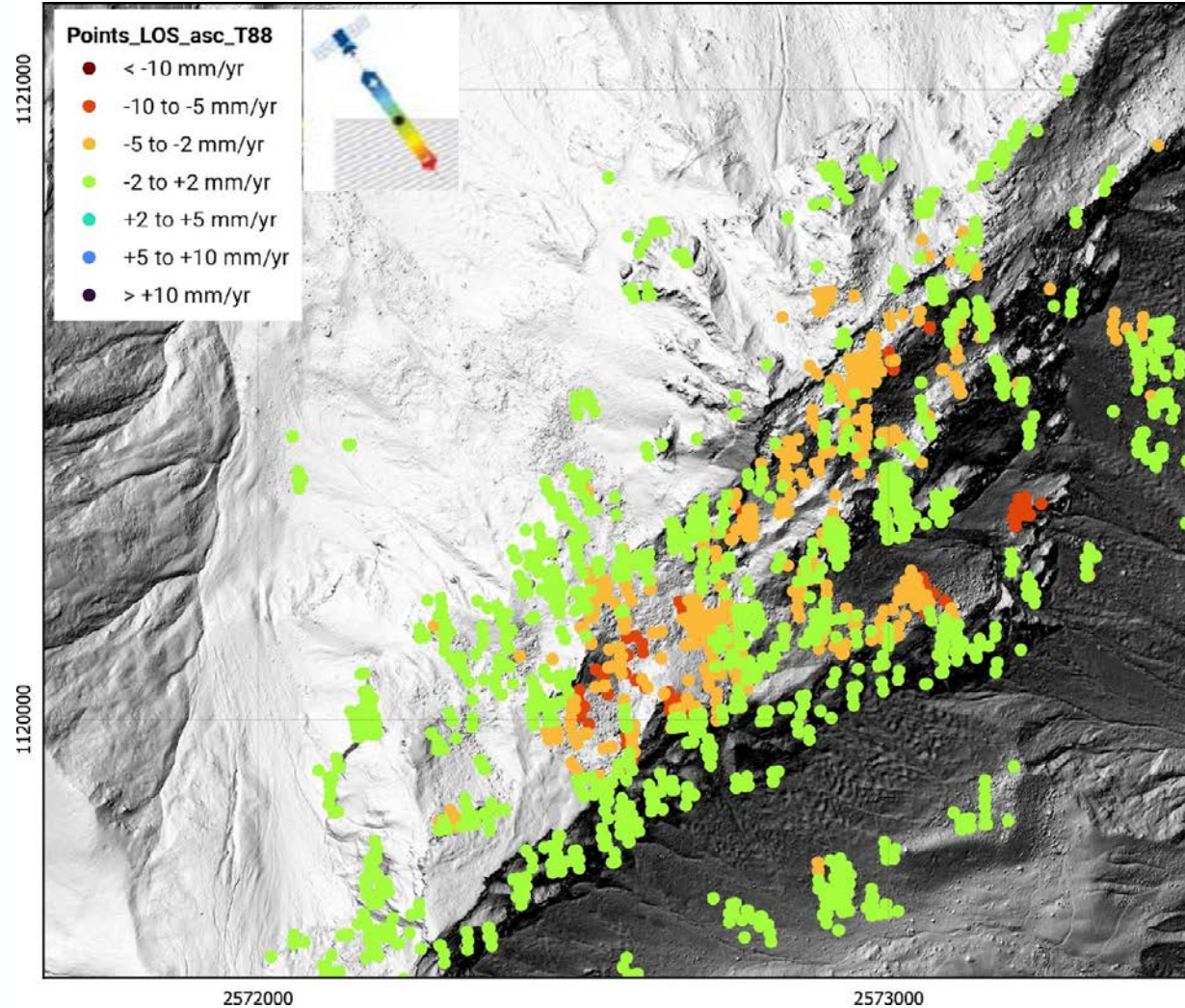
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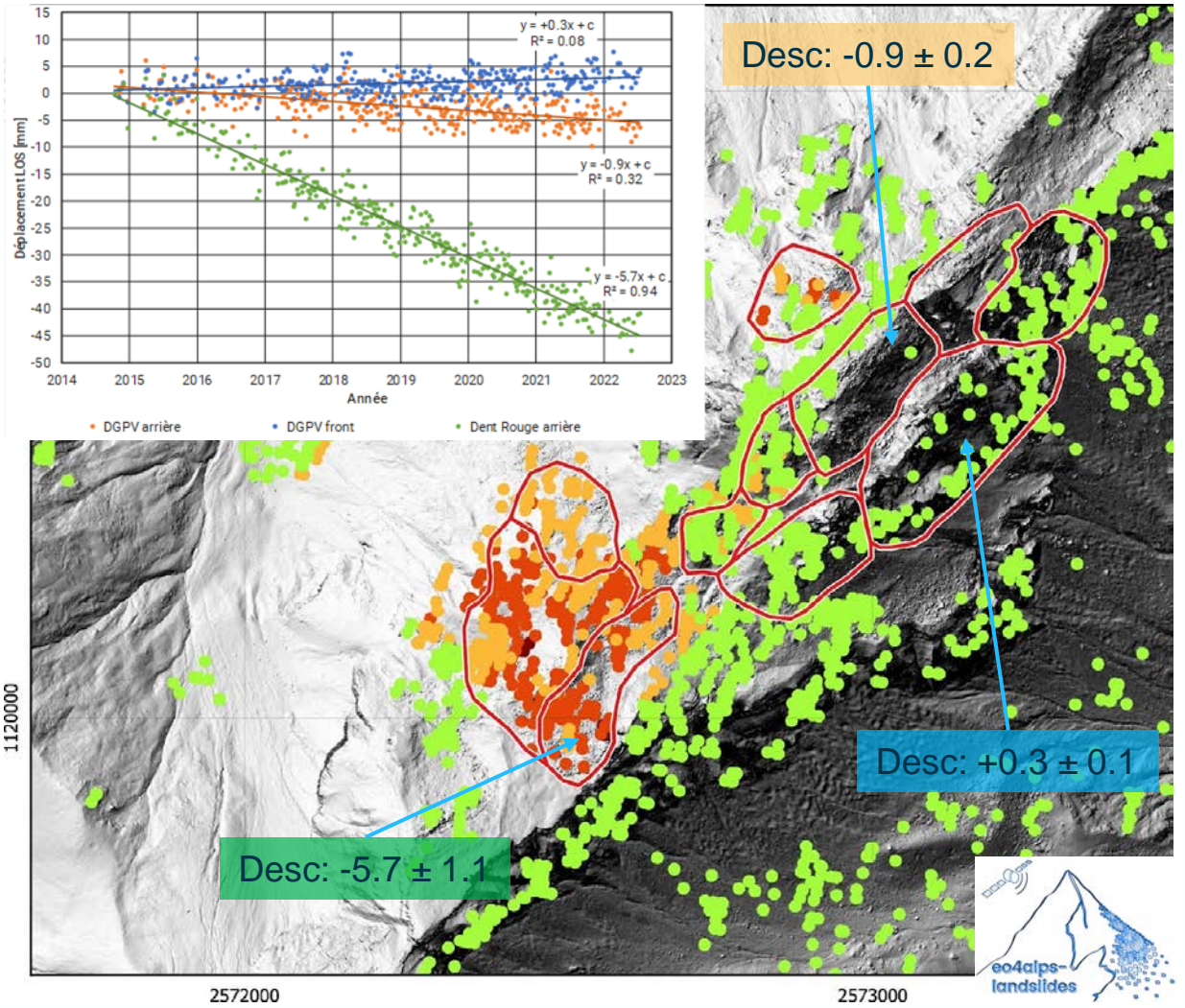
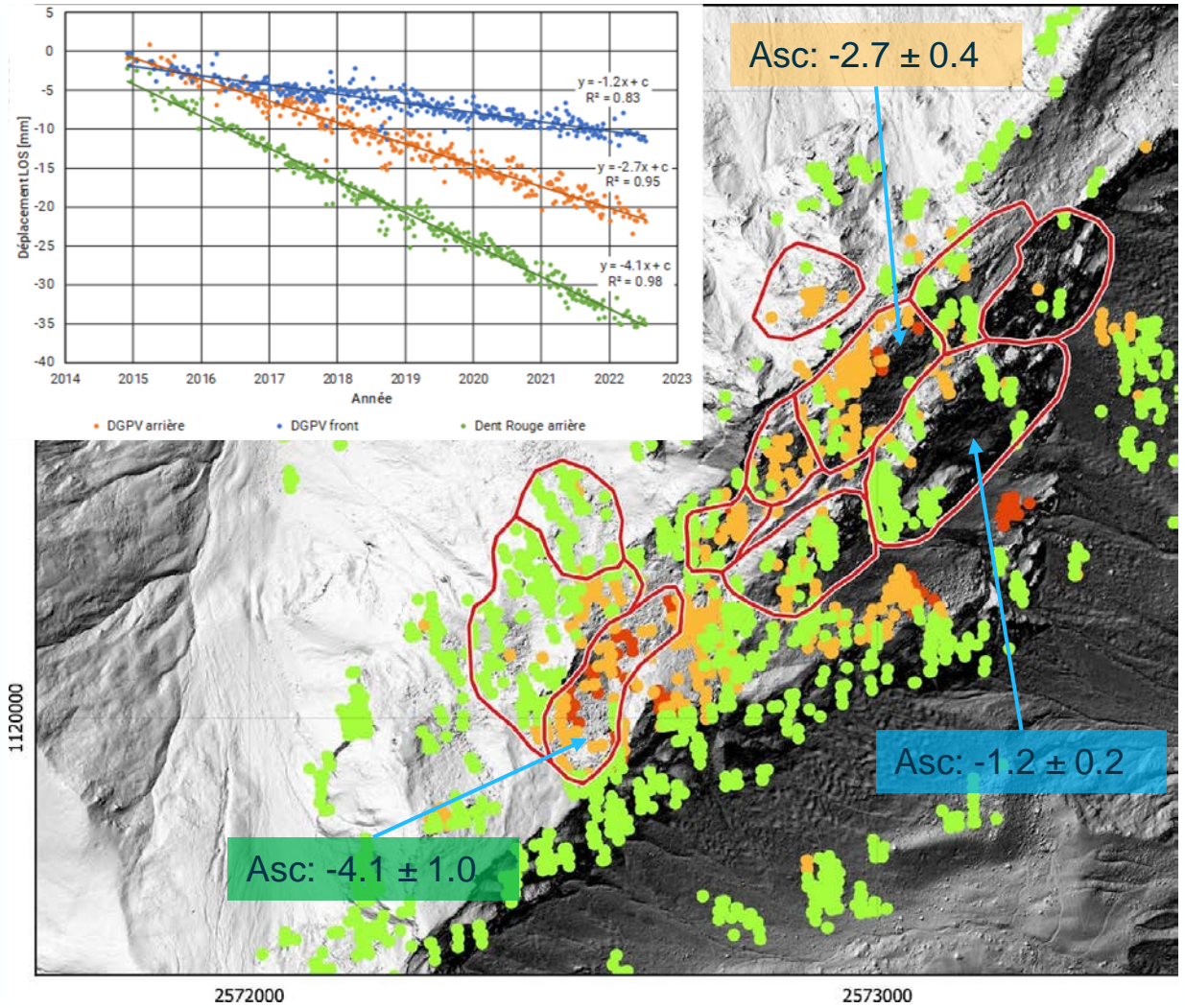


# Operational use case#1: InSAR ground-motion maps



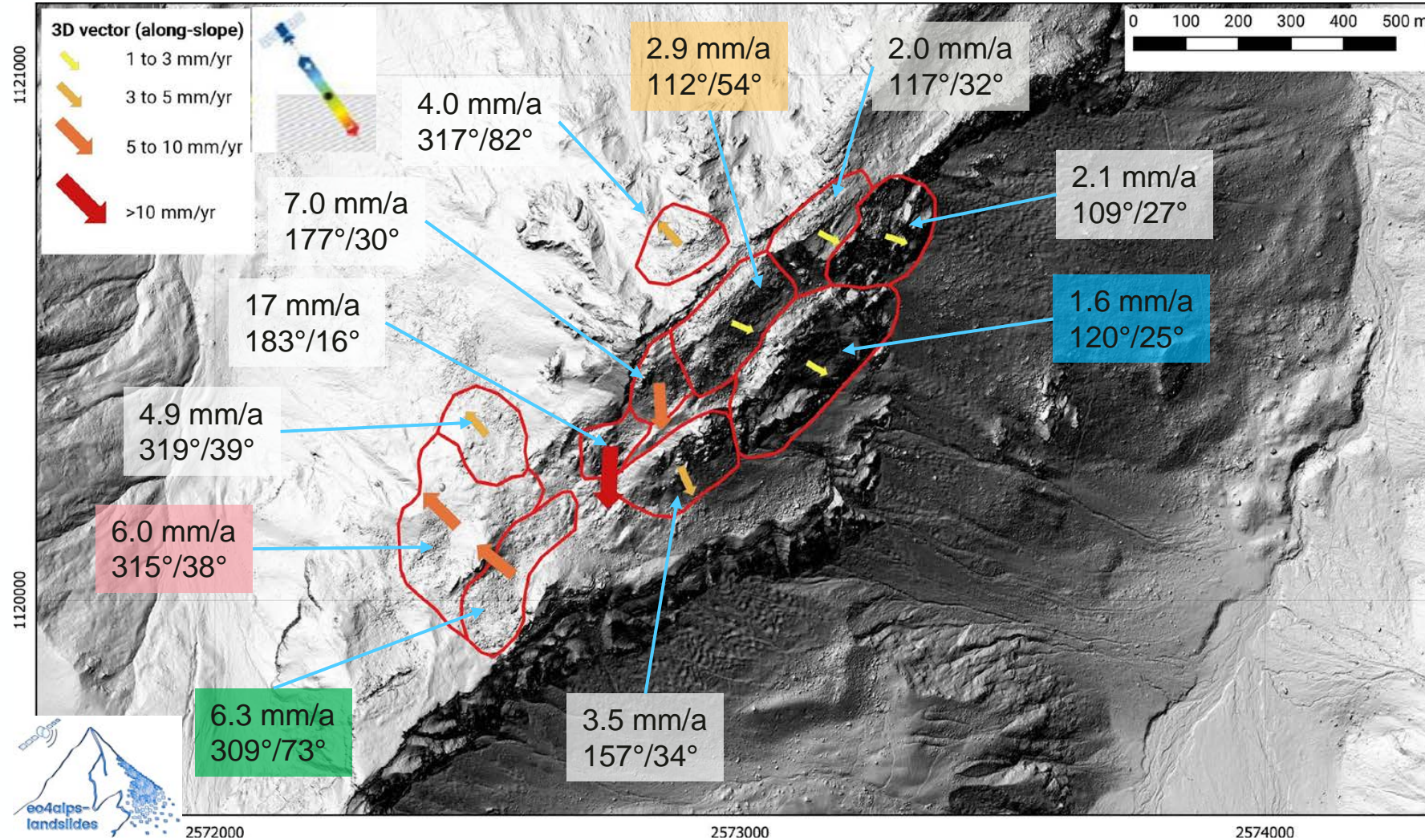


# Operational use case#1: InSAR ground-motion maps





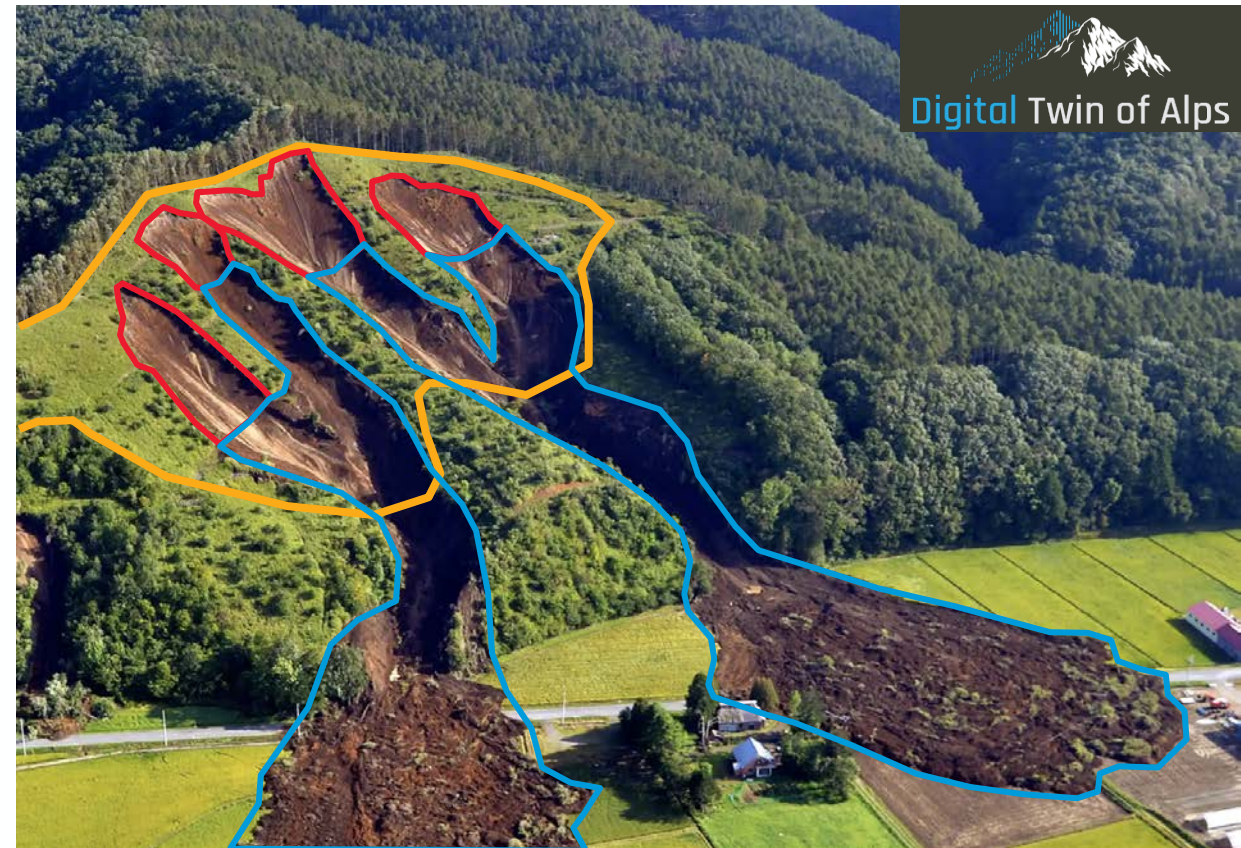
# Operational use case#1: InSAR ground-motion maps





# Operational use case #2: Forecasting shallow landslides

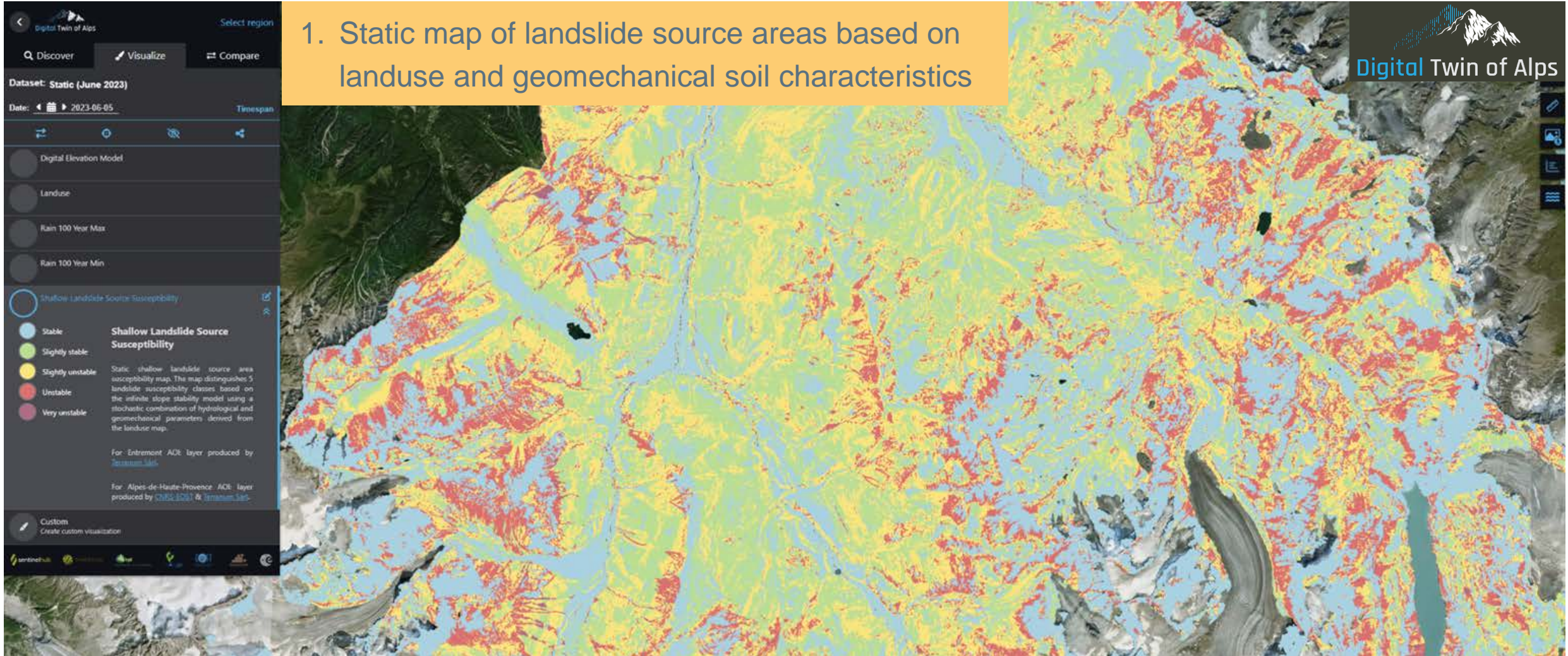
- The DTA shallow landslide forecasting chain is an automated service to spatially forecast, within 3 days leading time, the slope failure susceptibility and the landslide propagation after failure
- Three main processing steps
  1. Static map of landslide source areas based on landuse and geomechanical soil characteristics
  2. Forecast of landslide source areas that are prone to failure based dynamic triggering factors: weather forecasts along with EO-based models for snowmelt water input and soil moisture conditions
  3. Assessing the maximum runout areas for the forecasted landslide sources using the Flow-R propagation model for gravity-driven geohazards





# Operational use case #2: Forecasting shallow landslides

1. Static map of landslide source areas based on landuse and geomechanical soil characteristics





# Operational use case #2: Forecasting shallow landslides

2. Forecast of landslide source areas that are prone to failure based dynamic triggering factors



The screenshot shows the 'Digital Twin of Alps' web interface. At the top, there are navigation options: 'Discover', 'Visualize', and 'Compare'. The main content area displays 'Dataset: Forecast (June 2023 - now)' and 'Date: 2023-08-25'. A legend for 'Forecasted Precipitation' is visible, with a color scale from 0 to 100 mm. Below the legend, there are three radio button options: 'Shallow Landslide Forecasted Runout Areas', 'Shallow Landslide Forecasted Source Areas', and 'Custom'. The bottom left corner shows a satellite map of a mountainous region with a white outline indicating a specific area of interest.



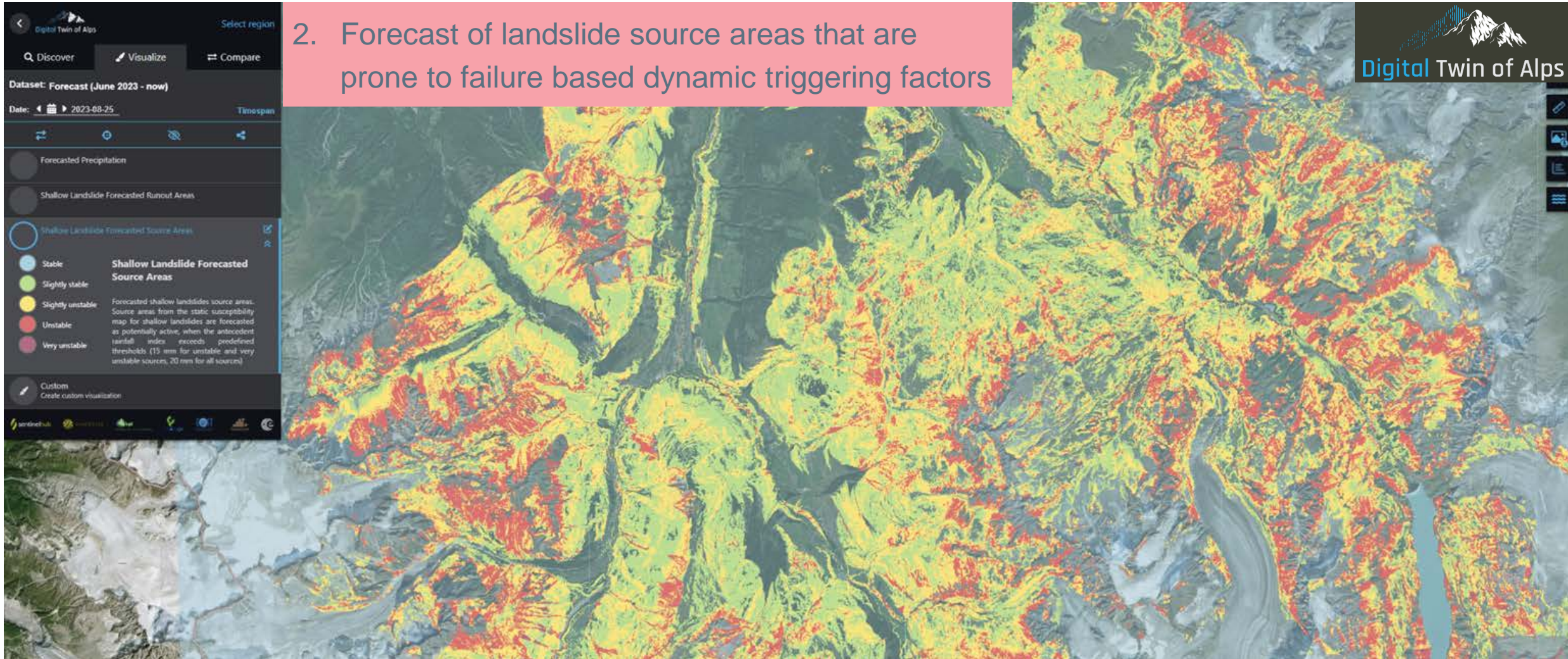
The 'Digital Twin of Alps' logo is located in the top right corner, featuring a stylized mountain range. Below the logo, there are several navigation icons: a pencil, a magnifying glass, a list, and a hamburger menu.





# Application 2: Forecasting for shallow landslides

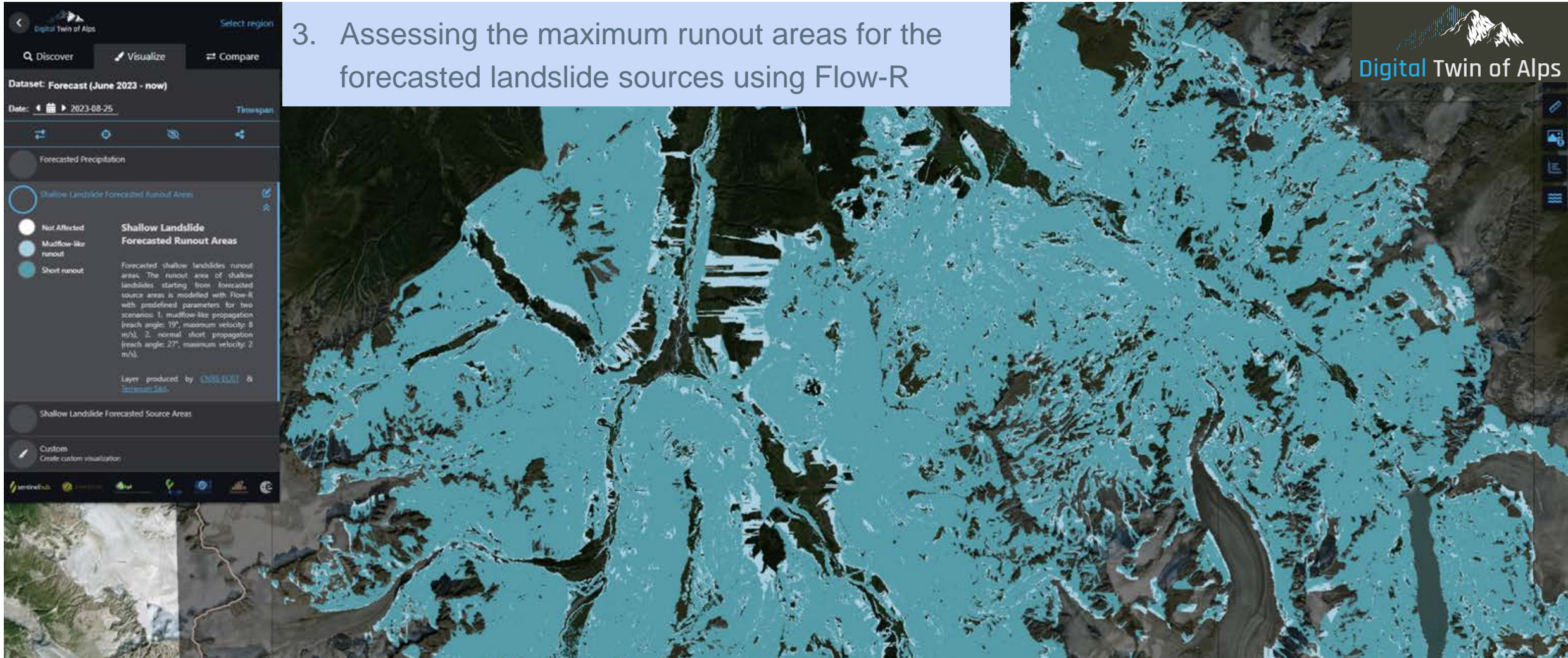
2. Forecast of landslide source areas that are prone to failure based dynamic triggering factors





# Operational use case #2: Forecasting shallow landslides

3. Assessing the maximum runout areas for the forecasted landslide sources using Flow-R





- The field of Earth observation has grown rapidly in recent years, both for optical/multispectral and radar satellites.
- ESA has launched several regional initiatives to increase and improve the use of satellite data in society in general, and more specifically among public authorities, private companies and research institutions.
- EO-based services and products will be more and more used
- It is important to know the possibilities, but also limitations of satellite-based EO data and products
- Numerous environmental applications related to Disaster Risk Management (DRM) and Resources (water):
  - Geohazards (landslides, earthquakes, volcanoes, subsidence)
  - Permafrost and glacier monitoring
  - Operational hydrology & water resources management (floods, droughts)



## GEP Processing Tutorials

- Processing tutorials
  - Active fire detection with Sentinel-3 SLSTR
  - ALADIM-HR and ALADIM-VHR: Preparation of input datasets
  - ALADIM-HR: Automatic Landslide Detection and Inventory Mapping from multispectral S2 & L8 data
  - ALADIM-VHR: Automatic Landslide Detection and Inventory Mapping from multispectral Very-High Resolution data
  - Avalanche Mapping with Sentinel-1 [norce]
  - Burned Area Analysis with Sentinel-2
  - Change Detection Analysis [VAL]
  - COIN - Coherence and Intensity change for Sentinel-1
  - COLOC - Multi-mission data co-location [VAL, cppp]
  - COMBI - Band Combination
  - DIAPASON InSAR - StripMap(SM)
  - DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW)
  - DLR Sentinel-1 InSAR Browse [VAL]
  - DSM-OPT: Digital surface models from optical stereo satellite images
  - FASTVEL for displacement velocity map generation
  - Flow-R: Flow Path Assessment of Gravitational Hazards at a Regional Scale [eo4alps]
  - GDM-OPT-ETC: Multiple Pairwise Image Correlation of OPTICAL images for EarThQuake analysis
  - GDM-OPT-ICE: Ground Deformation Monitoring with OPTICAL image Time series for ICE/glacier analysis
  - GDM-OPT-SLIDE: Ground Deformation Monitoring with OPTICAL image Time series for landSLIDE analysis
  - GMT5SAR InSAR - Stripmap
  - GMT5SAR InSAR - Sentinel-1 TOPSAR
  - Map Export [GEN]
  - P-SBAS Sentinel-1 processing on-demand by CNR-IREA
  - RASTER - Full Resolution Rasterization
  - S-1 SAR PIPE - Sentinel-1 Interferometric Processing Engine [EXP]
  - Sentinel-1 Level-1 GRD RGB composite
  - Sentinel-2 Multitemporal RGB composite with Gefolki coregistration
  - Sentinel-2 L1C and L2A RGB composite [eo4sd]
  - Sentinel-2 Watermask [cppp, wb, esa]
  - Sentinel-3 OLCI composite
  - Sentinel-1 Extended Timing Annotation Dataset [setap]
  - SNAC - SNAP S-1 GRD Amplitude Change
  - SNAPPING
  - SNAP CSK DInSAR
  - SNAP-InSAR - SNAP Sentinel-1 IW SLC Interferogram and Displacements
  - SRTM Digital Elevation Model [GEN]

## GEP Webinar #3 - Monitoring landslides from space

<https://www.youtube.com/watch?app=desktop&v=UfDFQm4hGkM>



## Training material

## Usage tips for expert/non experts

### Flyer with the pros/cons of the services

**eo4alps-landslides ground motion and modeling services**  
- eo4alps-landslides.eu -

Geo-information Services for Landslides in the Alps (eo4alps-landslides) has the objective to offer the possibility to exploit the potential of satellite data coupled to advanced modeling for landslide hazards assessment in the Alpine region.

It allows access to satellite data, satellite ground motion services and landslide modeling services for documenting and assessing landslide hazard at several spatial scales (region, municipality and slope). The document presents the on-line services accessible on the eo4alps-landslides thematic application of the Geohazards Exploitation Platform (GEP).

>> Ground Motion Services applicable to landslide studies

> List of satellite input data

The eo4alps-landslides app provides access to catalogs of Copernicus (Sentinel-, Sentinel-2) image time series and to VHR (very-high-resolution) optical satellite sensors (Pléiades, Spot6/7, PlanetScope). Other satellite data might be uploaded by the users from their own catalogs.

Type	Spatial res.
Copernicus Sentinel-1	Radar, C-band 5 x 20 m
Copernicus Sentinel-2	Optical Multispectr. per band: 10 m, 30 m
Airbus Pléiades	Optical Multispectr. Panchroma
Airbus SPOT6-7	Optical Multispectr. Panchroma
PlanetScope Dove Cubesat	Optical Multispectr.

### >> Tips for selecting the landslide ground motion and modeling services according to the users' needs

The synthetic tables below present the usage possibilities of eo4alps-landslide services for the different analysis scales (regional; local) and scopes (landslide inventory, monitoring, catalog and propagation analysis).

REGIONAL SCALE ANALYSIS									
Type	Scope	SNAPPING	P-SBAS	FASTVEL	SqueeSAR	GAMMA	ALADIM	MPIC	DSM-OPT
Ground motion services	Landslide inventory	🌱	🌱	🌱	🌱	🌱	🌱	🌱	🌱
	Landslide monitoring	🌱	🌱	🌱	🌱	🌱	🌱	🌱	🌱

Type	Scope	MOTION_Combi	LAND_Stat	VOLTOO	FLOW-R
Hazard modeling services	Landslide catalog analysis	🌱	🌱	🌱	🌱
	Landslide propagation analysis	🌱	🌱	🌱	🌱

<b>Ground Motion Service: DSM-OPT</b>	<b>Input data:</b> Pléiades stereo/tri-stereoscopic images
<b>DSM-OPT</b>	<b>Description:</b> "Service designed to generate Digital Surface Models (DSM) and orthoimages from Pléiades acquired in several modes and viewing geometries."
<b>Service owner:</b> CNRS – École et Observatoire des Sciences de la Terre – Université de Strasbourg (France)	
<b>Service support:</b> <a href="mailto:dsm-opt@eo4alps-landslides.eu">dsm-opt@eo4alps-landslides.eu</a>	
<b>Use case 1:</b> High resolution topography of the Ubaye Valley (South French Alps) from Pléiades stereoscopic images.	
<b>On-line public results:</b> <a href="#">Here</a>	

Left: Hillshade of the Pléiades generated DSM over the Ubaye valley. Top left: Quality indicator map (the more red, the high accuracy). Top right: Pléiades generated DSM over the Ubaye valley.

Description of the services and access to public jobs

### Guidelines to select the service per use case

Technical specifications (performance of the service for the application)	Suitability for landslide application
Excellent	Highly designed for the application
Under specific conditions	Relevant with a little knowledge
Poor	Relevant in specific cases for experienced users
Not relevant	Not relevant

**Technical specifications**

- Sensitivity to EW medium
- Sensitivity to NS medium
- Sensitivity to vertical motion
- Visual interpretability of results
- Resolution of outputs
- Multi sensor analysis
- Time series analysis

**Suitability for landslide application**

- Fast moving landslides (> 5 cm.day<sup>-1</sup>)
- Slow-moving landslides (< 2 cm.day<sup>-1</sup>)





[eo4alps-landslides.eu](http://eo4alps-landslides.eu)

[digitaltwinalps.com](http://digitaltwinalps.com)

# Thank you for your attention

Please contact us for more information and access to our services and products:

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