Landslide Demonstrator 2021-2024

CEOS

"EO-based Landslide services: Paving the Way for Landslide Hazard Management Products"

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Objectives of the Landslide Demonstrator

Propose landslide tailored tools, services, products and geo-information to support landslide hazard and risk assessment for several end user communities

- **Application 1**: Engage with stakeholders for promoting the use of satellite data for landslide disaster assessment and mitigation along **transportation and pipeline corridors**, with goal of establishing **local monitoring systems**

- **Application 2:** Engage with stakeholders for establishing **landslide hazard and risk forecasts,** using **satellite data** and **models**

- **Application 3:** Coordinate and expand the availability of landslide inventories and supporting data to advance **landslide science** at global scale, with the **systematic documentation of large landslide disasters triggered by extreme forcing events**

Application #1:
EO-based operational landslide monitoring

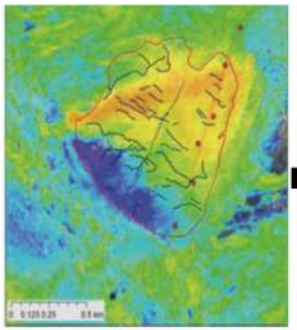
How to engage with users to establish local monitoring systems using EO?

Implement and propose to users a portfolio of landslide-tailored services for landslide hazard assessment at both regional and local scale analyses.

"eo4alps-landslides" products delivered to end-users

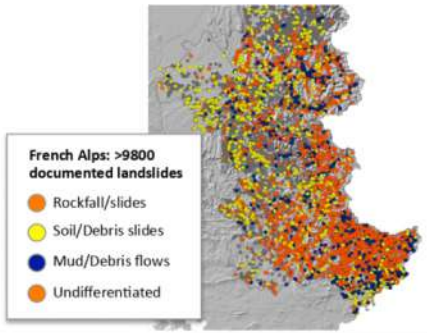
- on-demand/systematic landslide detection/ground motion using satellite optical/InSAR services
- harmonised and advanced landslide catalogues
- susceptibility/hazard maps consisting of possible landslide source and runout areas, through modelling

Product #1



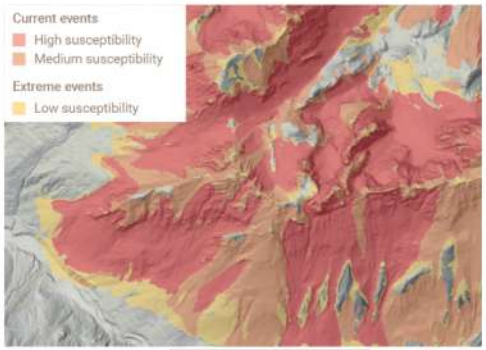
ground motion maps

Product #2



inventory maps

Product #3

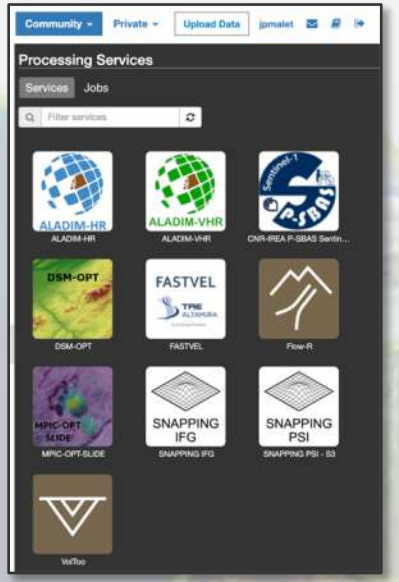


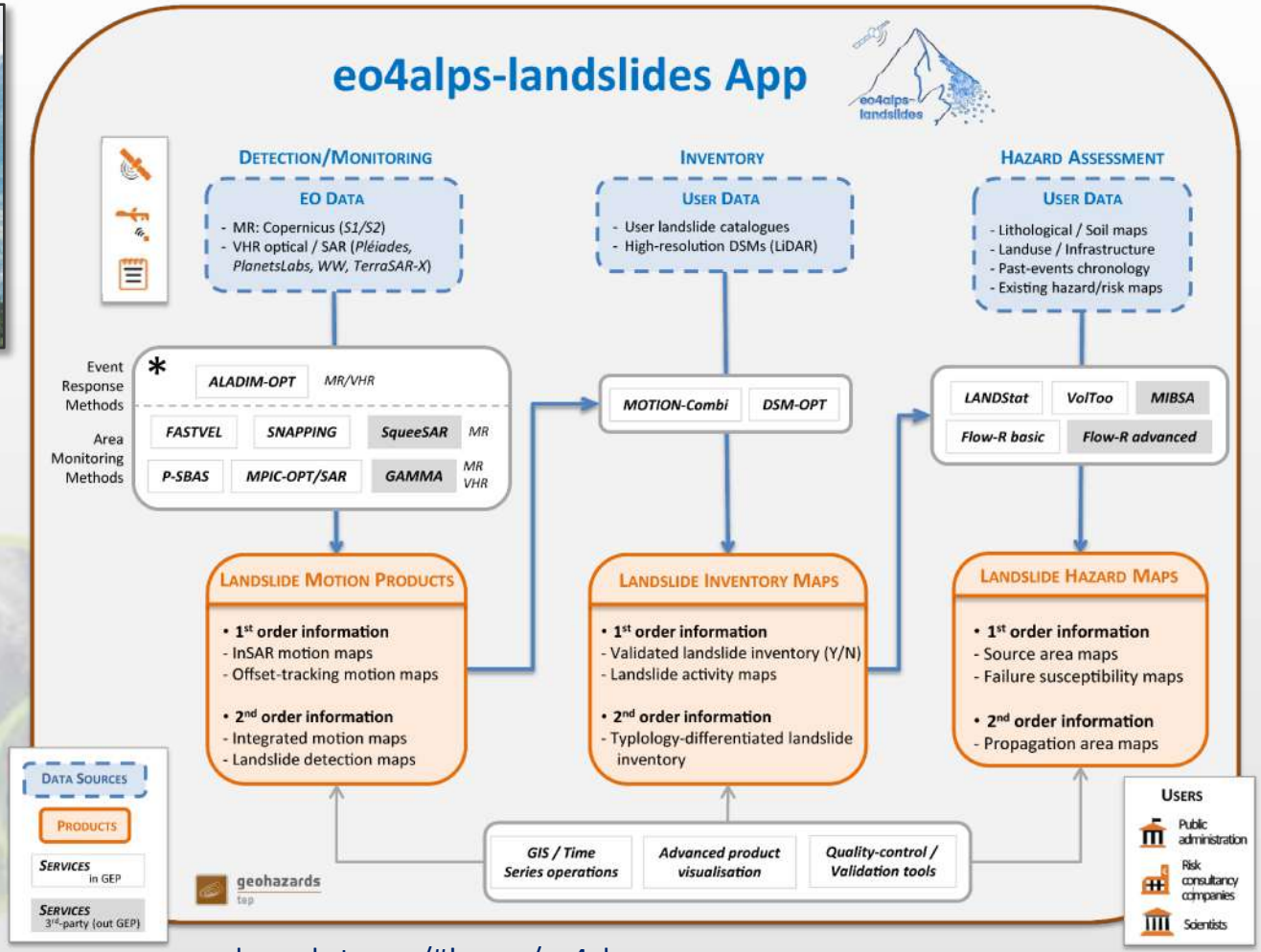
hazard maps

www.eo4alps-landslides.eu

Application #1:
EO-based operational landslide monitoring

A state-of-the-art portfolio of services integrated on cloud-based environments





geohazards-tep.eu/#!pages/eo4alps

Application #1: EO-based operational landslide monitoring

Flyer with the pros/cons of the services

eo4alps-landslides

European Space Agency

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 re
Copernicus Sentinel-1	Radar, C-band	5 x 20 m
Copernicus Sentinel-2	Optical	Multispect per band): 10 m, 30 m
Airbus Pléiades	Optical	Multispect Panchroma
Airbus SPOT6-7	Optical	Multispect Panchroma
PlanetScope Dove Cubesat	Optical	Multispect

>> 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	✗	✗	✗	✓

Training material and capacity building

Ground Motion Service: DSM-OPT

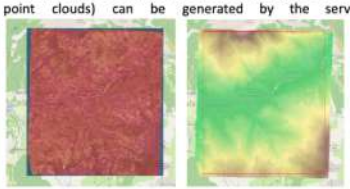
Input data: Pléiades stereo/tri-stereoscopic images

DSM-OPT

Description: Service designed to generate Digital Surface Models (DSM) and orthoimages from Pléiades acquired in several modes and viewing geometries.

Service owner: CNRS – École et Observatoire des Sciences de la Terre – Université de Strasbourg (France)
Service support: dsm-opt@eo4alps-landslides.eu
Use case 1: High resolution topography of the Ubaye Valley (South French Alps) from Pléiades stereoscopic images.
On-line public results: Here

The service DSM-OPT has been used to generate the relief at high spatial resolution (1 m) and relative accuracy in elevation (ca. 1.5 m) from a tri-stereoscopic Pléiades acquisition over the Ubaye valley (South French Alps) where the La Valette, Sanières and Super-Sauze landslides are located. Products such as the Digital Surface Model (DSM) a quality assessment criteria (coefficient of correlation), and downstream products (such as hillshade maps, and elevation point clouds) can be generated by the service.

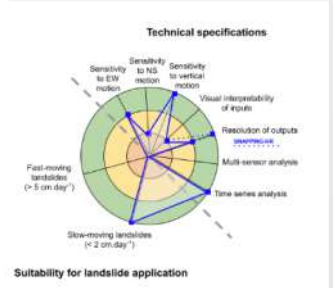


Left: Hillshade of the Pléiades generated DSM over the Ubaye valley. Top left: Quality indicator map (the more red, the high

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

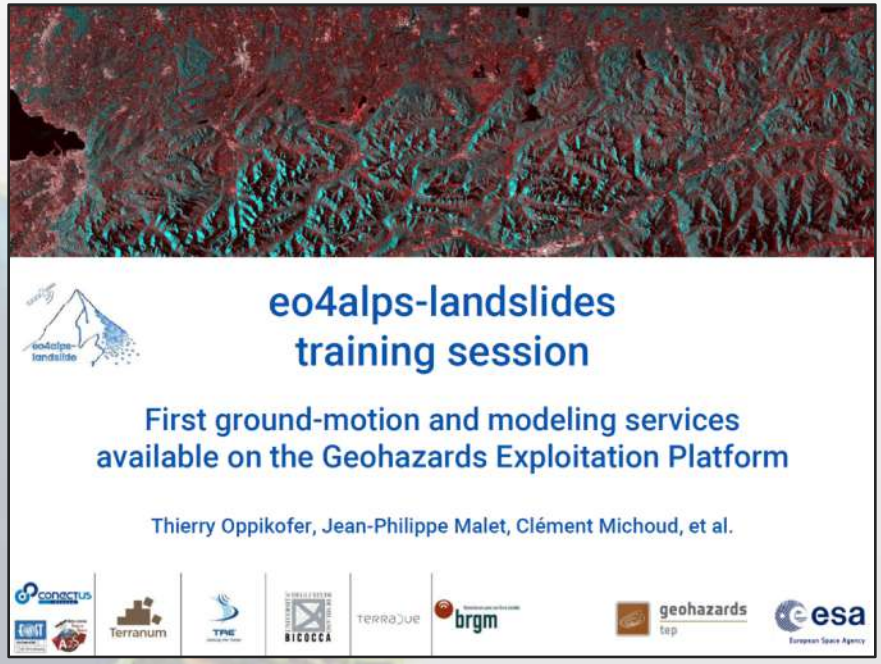


Application #1: EO-based operational landslide monitoring

Training sessions for categories of landslide users

Training sessions for users of the eo4alps-landslides App were held in April/May 2022 (documentation in Powerpoint & live online demonstration on GEP)

- 2 sessions in French for 11 users
- 1 session in German for 6 users
- 1 session in English/Italian for 1 user
- 5 sessions external to the eo4alps-landslide community (Portugal, Canada, Belgium, Philippines, Azerbaïdjan)



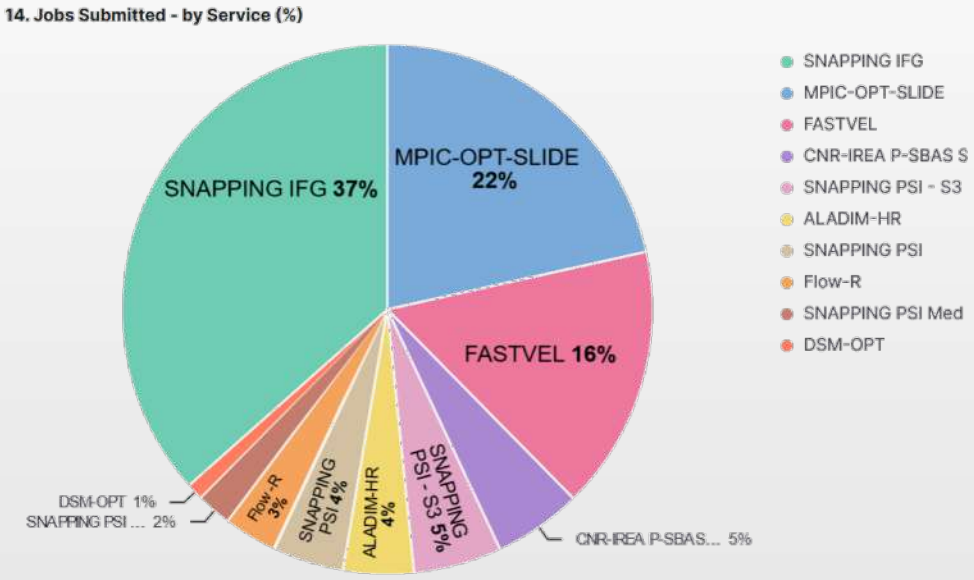
Access to the App granted by ESA/NoR initative

Country	Organization
France	Office National des Forêts
France	Office National des Forêts
France	SAGE srl.
Italy	Regione Valle d'Aosta
Switzerland	Canton de Vaud
Austria	Geologische Bundesanstalt
Austria	Geologische Bundesanstalt
Austria	Wildbach- und Lawinenverbauung
Austria	Wildbach- und Lawinenverbauung
Austria	Georesearch Forschungsgesellschaft mbH
Austria	Georesearch Forschungsgesellschaft mbH
Switzerland	Canton de Fribourg
Switzerland	Canton de Fribourg
Switzerland	Canton du Valais
Switzerland	CREALP
Switzerland	Norbert SA
Switzerland	Norbert SA
Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale

Application #1:
EO-based operational landslide monitoring

Outcomes and preliminary feedbacks from the user tests

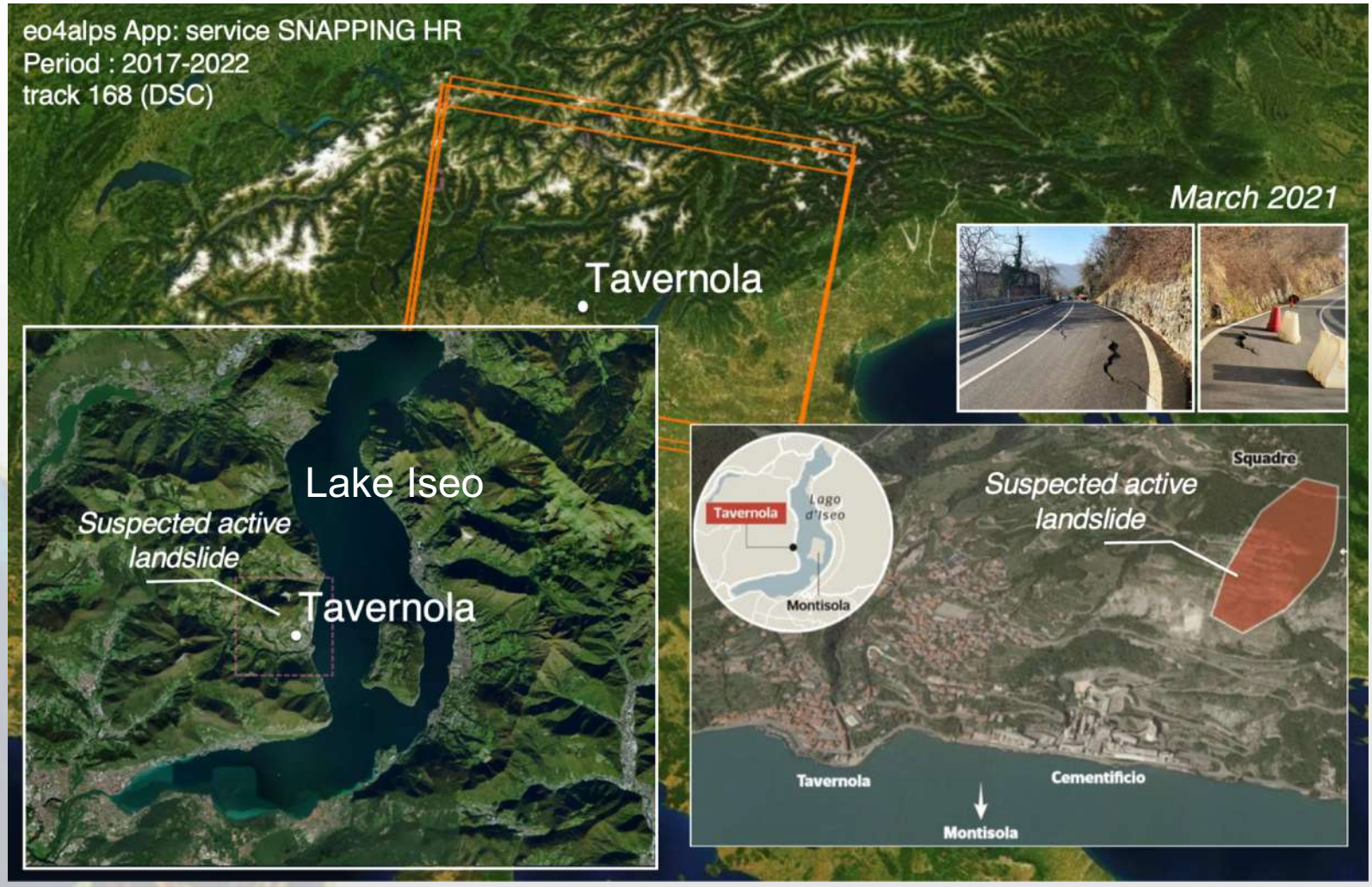
- After the training sessions, users received the complete documentation and were invited to test the available services
- From June to September 2022: assistance to the users in testing the services
- Most used ground motion services:
  - SNAPPING
  - GDM-OPT-SLIDE
  - FASTVEL
  - P-SBAS
- Sentinel-1 and Sentinel-2 usage statistics



extracted from GEP dashboard (Kibana)

Application #1:
EO-based operational landslide monitoring

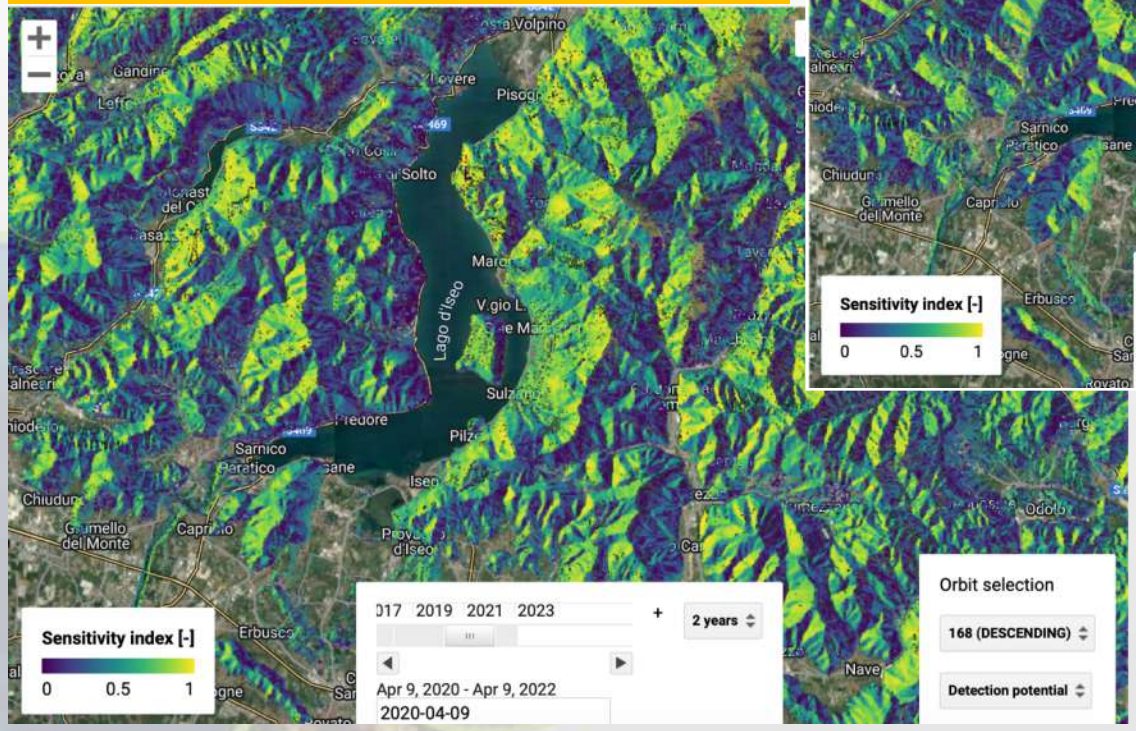
#1: Support/explain the products and implement quality-control / error estimates

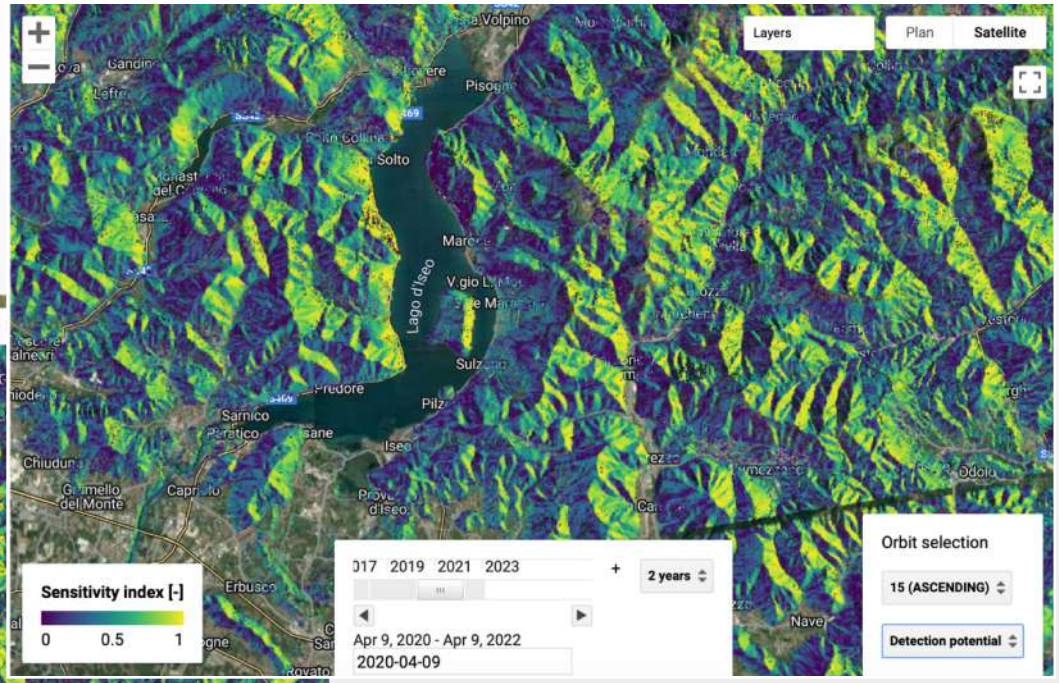


Application #1:
EO-based operational landslide monitoring

#1: Support/explain the products and implement quality-control / error estimates

InSAR sensitivity index for landslide deformation analysis

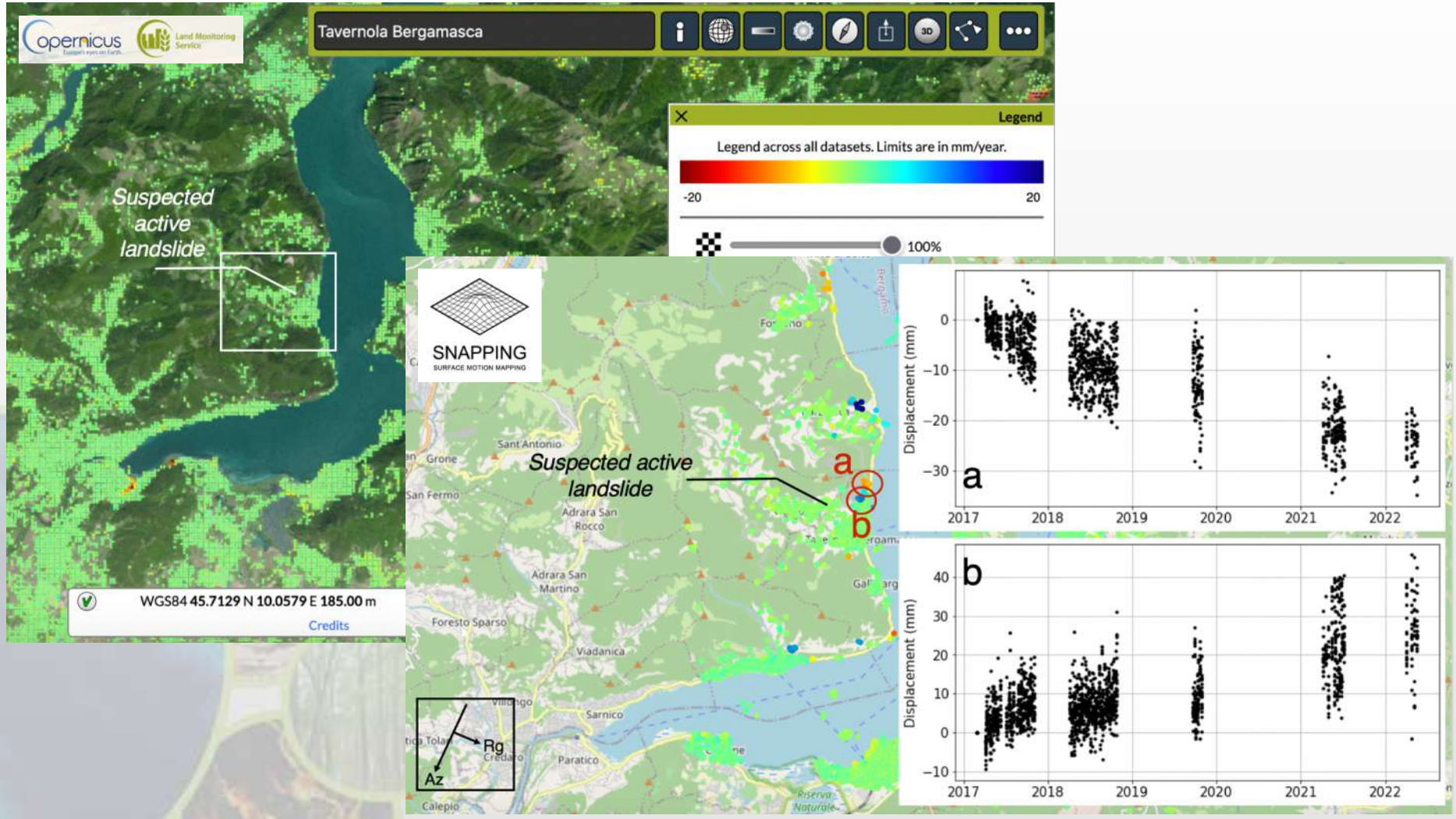




Help the non-expert users to understand the deformation signals

Application #1:
EO-based operational landslide monitoring

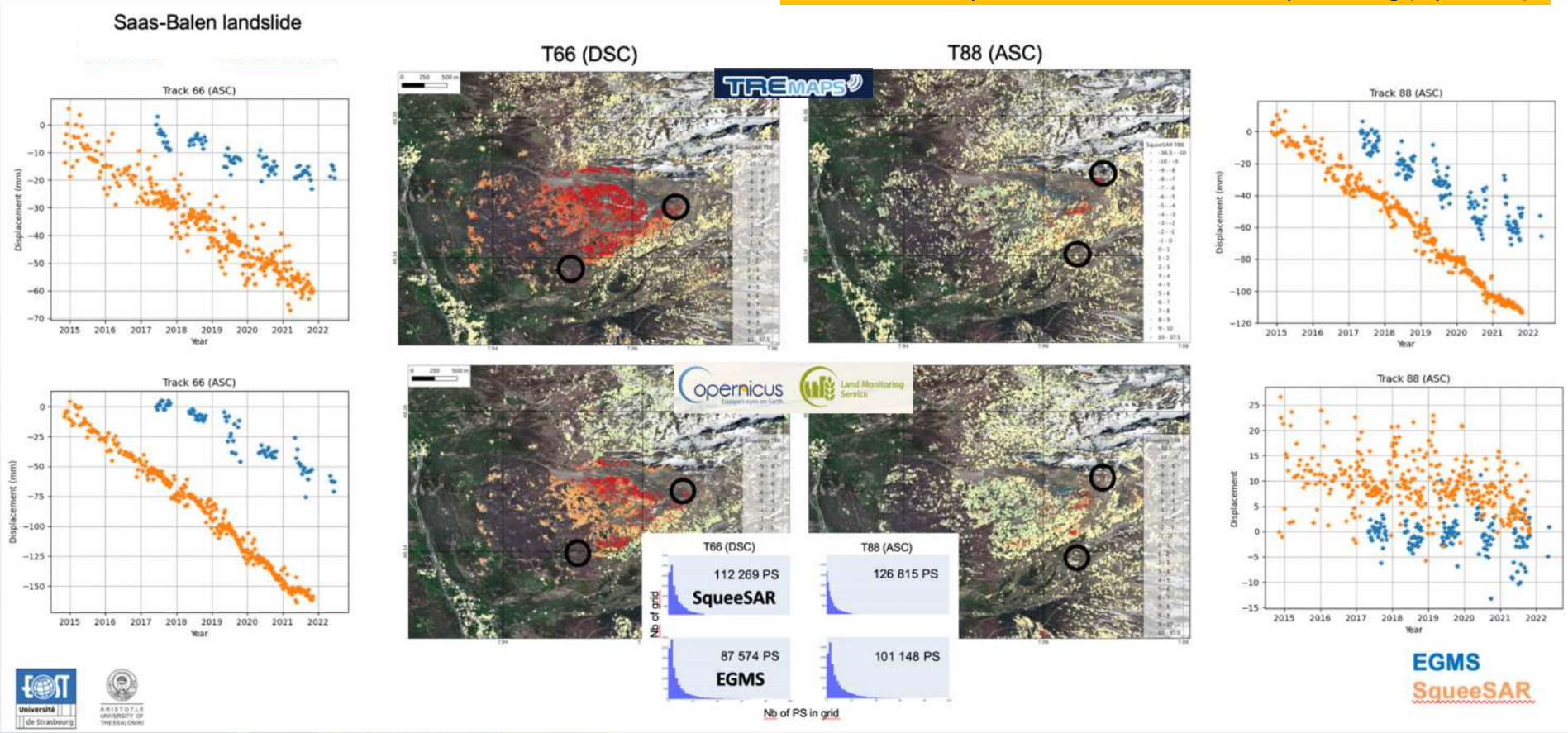
#1: Support/explain the products and implement quality-control / error estimates



Application #1:
EO-based operational landslide monitoring

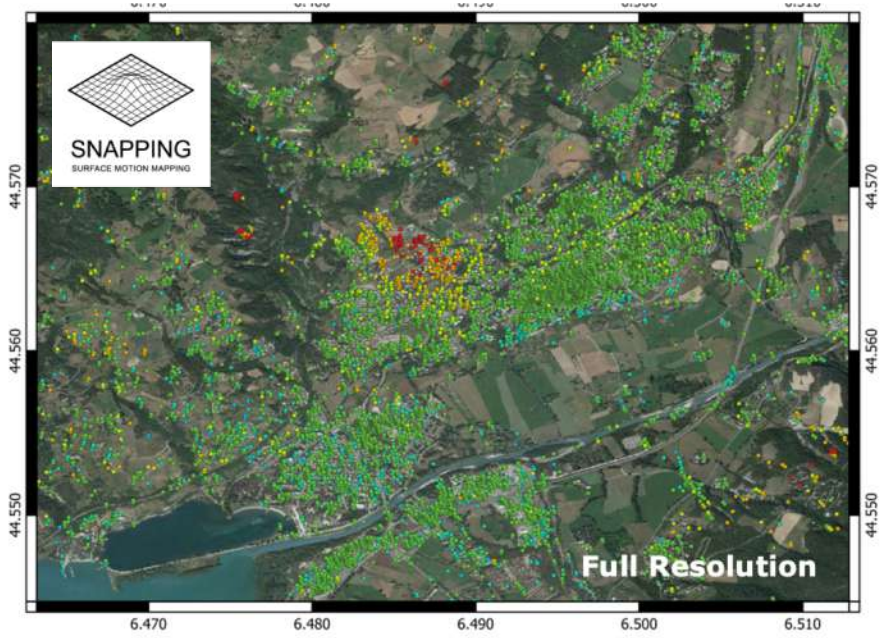
#1: Support/explain the products and implement quality-control / error estimates

Same processors with different parameterizations
EGMS standard product vs. tailored landslide processing (SqueeSAR)



Application #1: EO-based operational landslide monitoring

#2: Integrate in-situ measurements (validation of EO products, higher quality processing)



SNAPPING PSI [mm/yr]
- -60 - -40
- -40 - -20
- -20 - -10
- -10 - 10
- 10 - 20
- 20 - 40
- 40 - 60

0 500 m

Sentinel-1 Track:
Ascending 088

Observation Period:
6-months period in 2020

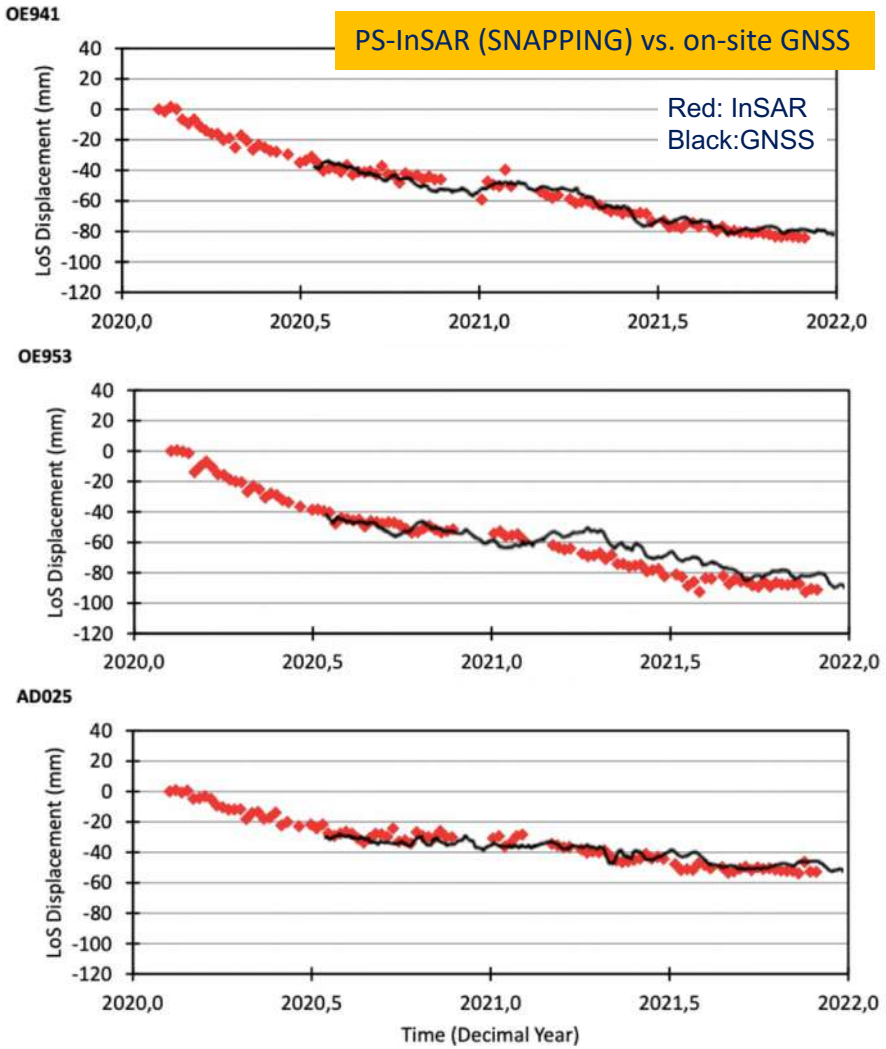
Temporal Constraints:
From May to Oct

Nu of Sentinel-1 Scenes:
28 (6-days repeat)

Nu of PS points:
10417

Max Terrain Motion Rate:
-55.4 mm/yr

PS-InSAR (SNAPPING) vs. on-site GNSS

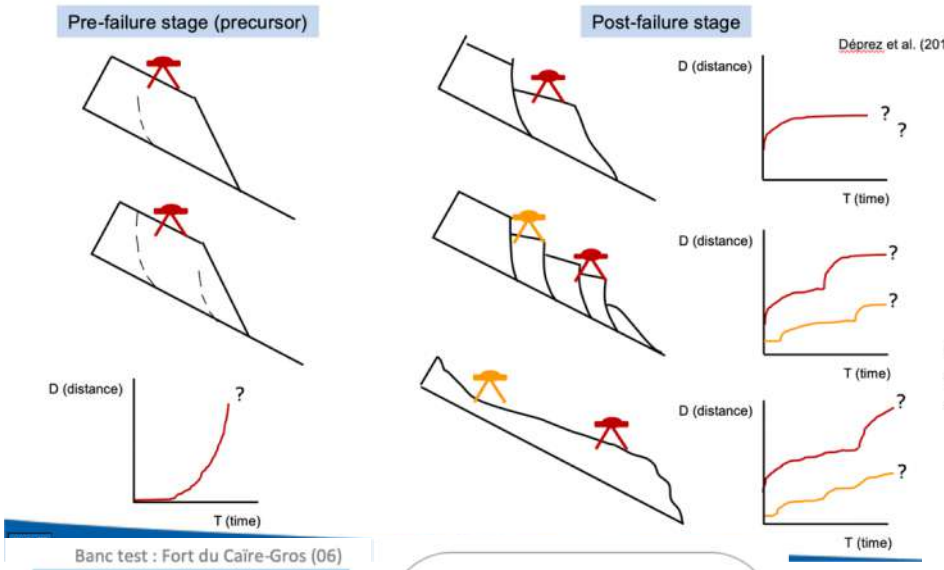


Application #1: EO-based operational landslide monitoring

#2: Integrate in-situ measurements (validation of EO products, higher quality processing)

GNSS for landslide surface motion monitoring
- precise, continuous and consistent measures of landslide displacement
- various landslide types, regime, spatial variability of the motion pattern

More and more landslides instrumented with GNSS (geodetic and low-cost receivers)



Advantage of **satellite EO** acquisitions:
- non invasive
- monitoring of remote areas
- large spatial coverage

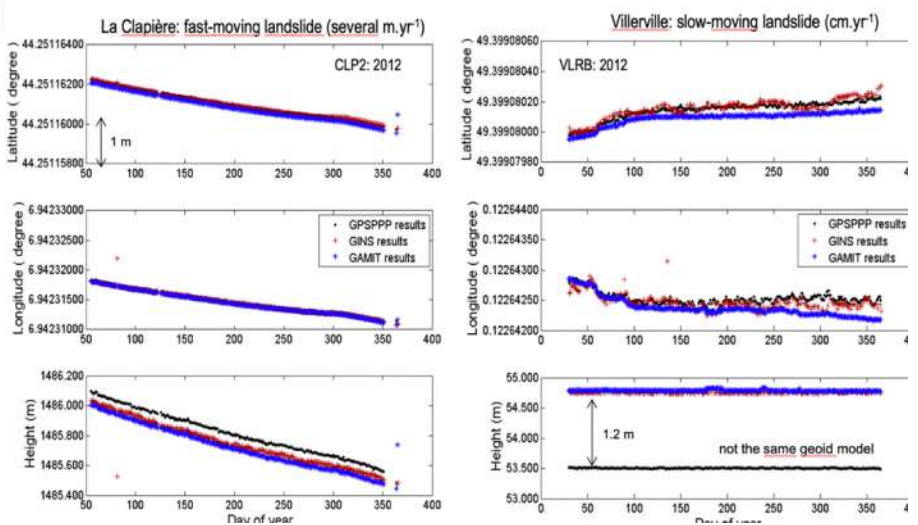
Advantage of **GNSS** acquisitions:
- reference measurements
- all weather, 365/24 and high frequency rates
- 3D component of the motion

High-grade receivers

Récepteur GNSS bi-fréquence Ublox F9P
- Multi-constellations: GPS, Glonass, Galileo et Beidou
- Seulement la moitié des satellites GPS exploitables en bi-fréquence
- Antenne avec fiche de calibration ANTEX
- Solution centimétrique en mode RTK

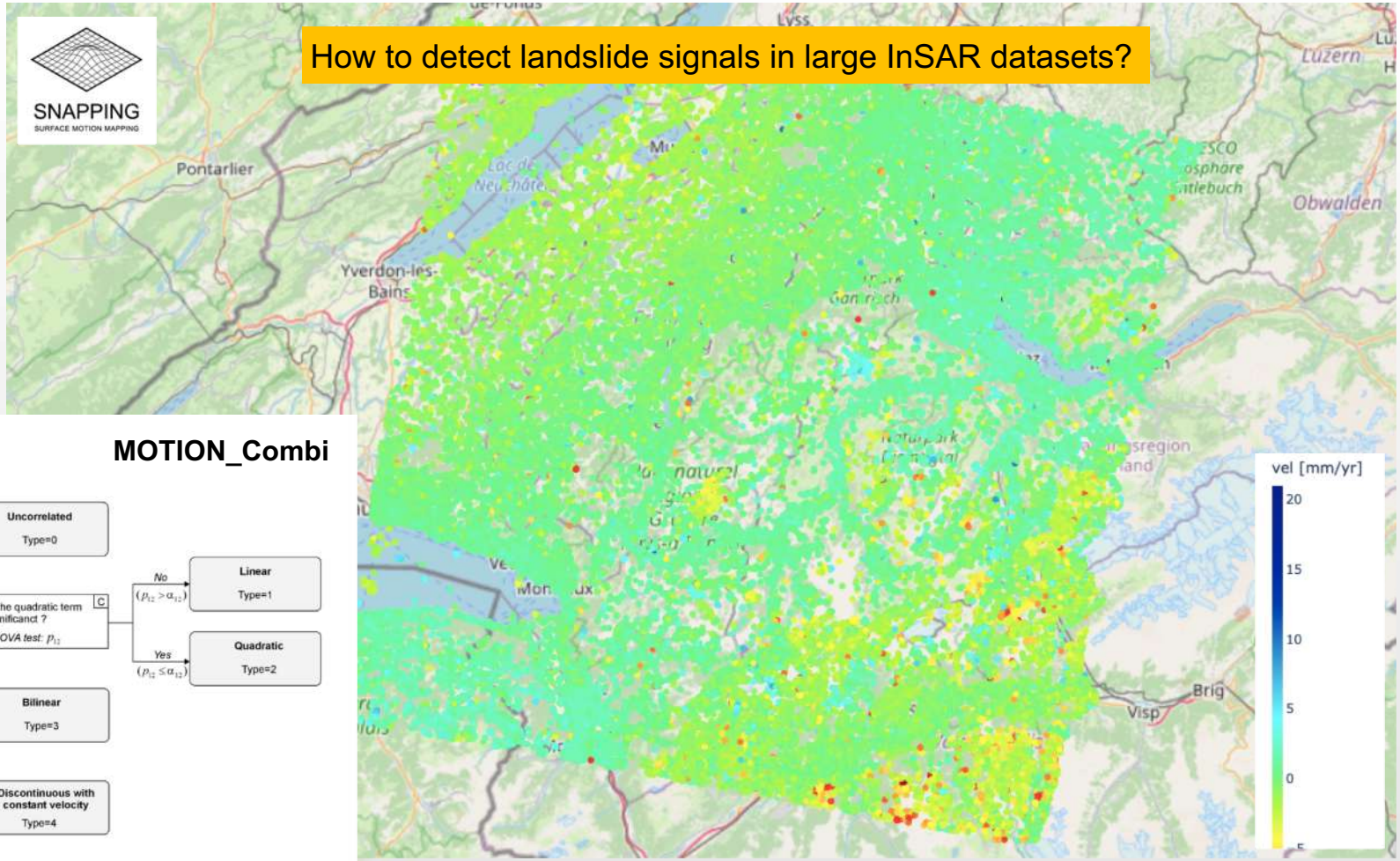
Low-cost receivers

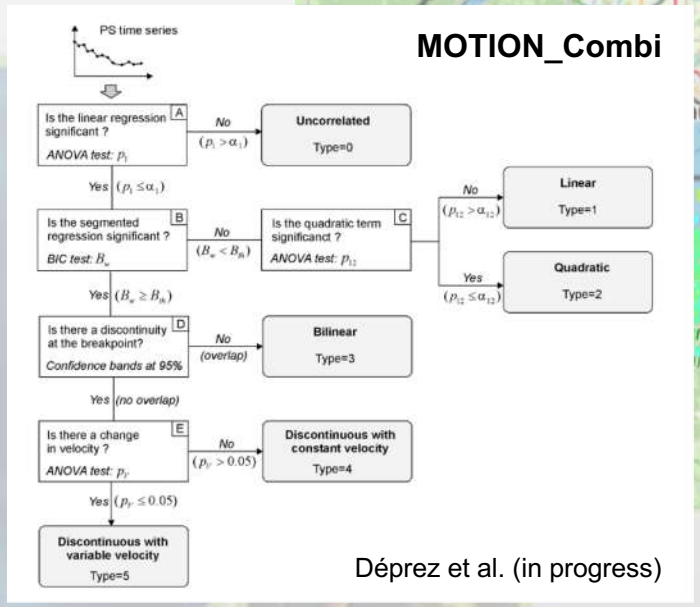
GNSS observations: test of several processing methods
- DD (double differencing – Gamit, RTKLib, Bernese, GipsyX)
- PPP (precise point positioning – GINS, SCRS-PPP)



Application #1:
EO-based operational landslide monitoring

#3: Provide tools for ground-motion product post-processing





Déprez et al. (in progress)

Application #1:
EO-based operational landslide monitoring

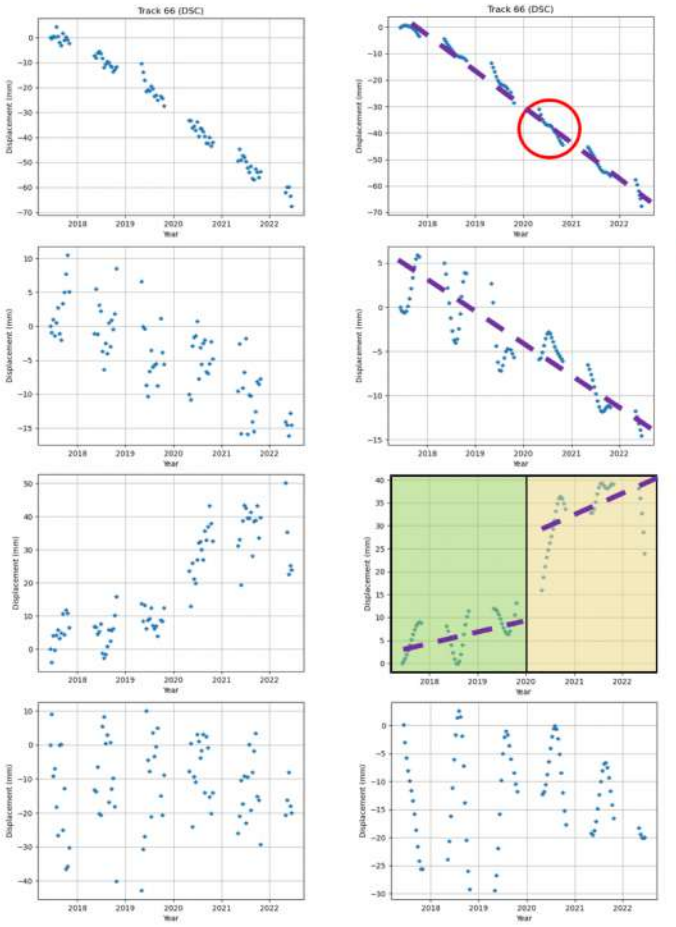
#3: Provide tools for ground-motion product post-processing

Dataset filtering: low-pass filter

Break detection

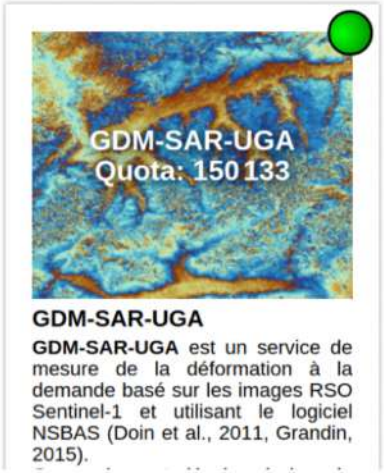
Trends detection : first discrimination between time series
(uncorrelated / linear / bi-linear / …)

Seasonality analysis : intra annual and inter annual analysis
(stack of all the years to improve the knowledge of the "standard" annual pattern, detection of year which deviates from the standard, …)

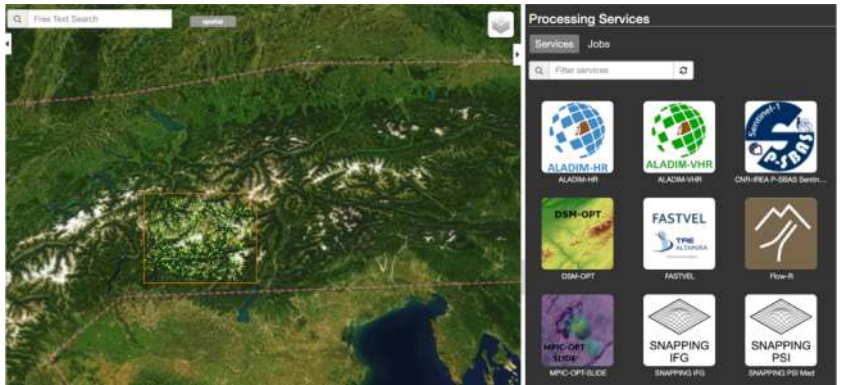


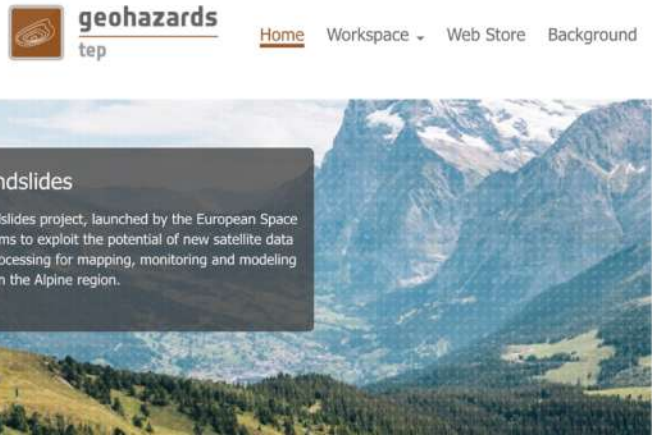
#4: Provide a diversity of processing environments
Work on a Business Model

Simple: 1 processing chain <> 1 webservice



Complex: Portfolio of services on a platform <> GEP





Application #1:
EO-based operational landslide monitoring

#5: OTELO

PPP approach
Science – Private Risk Engineering Company

CIFRE / PhD – B. Wirtz

connect by cnes — Space Tour 2021
Les applications spatiales : Tremplin pour l'Economie et la Société

SAGE INGENIERIE — EOST Université de Strasbourg

OTELO

Outils de TELédétection opérationelle des mOuvements de terrain

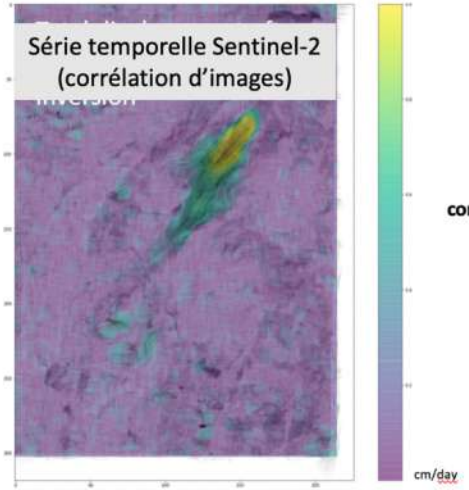
Images satellite multi-spectrales / optiques

- Vitesse rapide (> cm/jour)
- Composante horizontale du mouvement

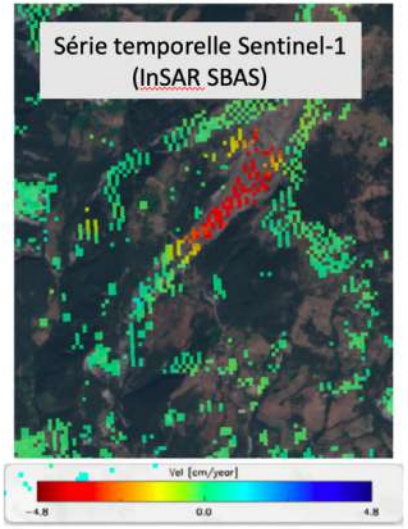
Images satellite SAR

- Vitesse lente (mm/jour)
- Composante verticale (et E-W) du mouvement

Glissement de terrain de La Valette
(Ubaye, Alpes-de-Haute-Provence)



complémentarité



Application #1: EO-based operational landslide monitoring

#5: OTELO

PPP approach
Science – Private Risk Engineering Company

Market Analysis:
O. Brenguier

connect by cnes Space Tour 2021
Les applications spatiales : Tremplin pour l'Economie et la Société

OTELO
Outils de TELédétection opérationelle des mOuvements de terrain

Expertise en traitement des données satellites
Développeur des algorithmes

collaboration > 15 ans

Expert terrain : géologie, géophysique et risques naturels
Adaptation des produits académiques à l'usage opérationnel
Exploitation des produits

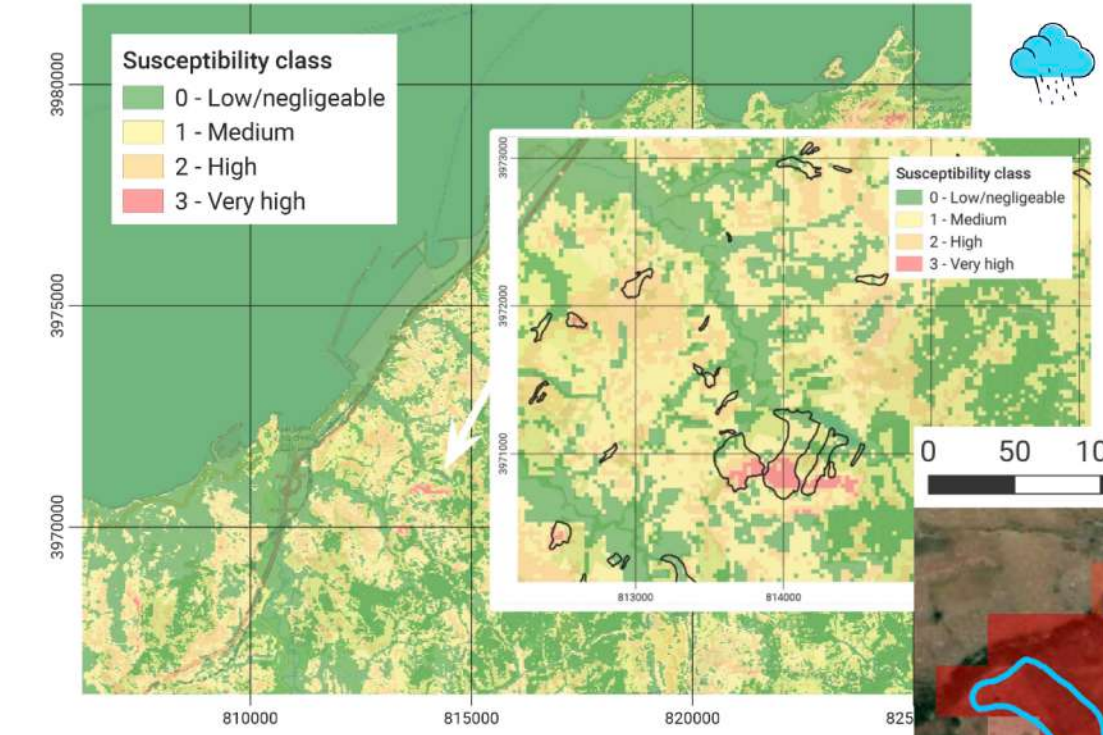
Béta-testeurs des produits OTELO

Modèle économique

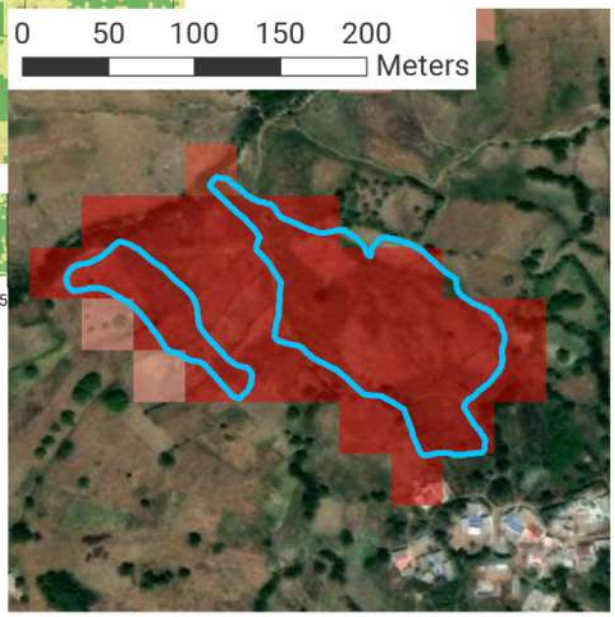
Nouveaux marchés

Application #2:
Landslide Disaster Risk Products

Can we propose models to forecast landslide disasters? (World Bank / LHIS-P)



Terranum USRA terra due



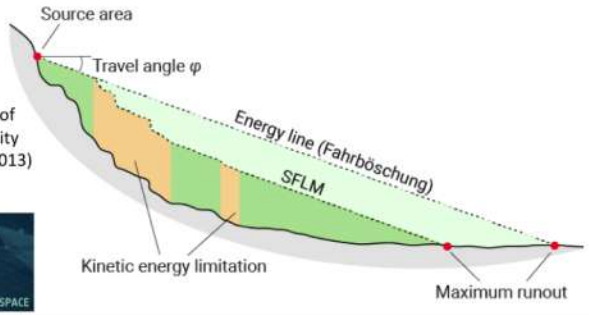


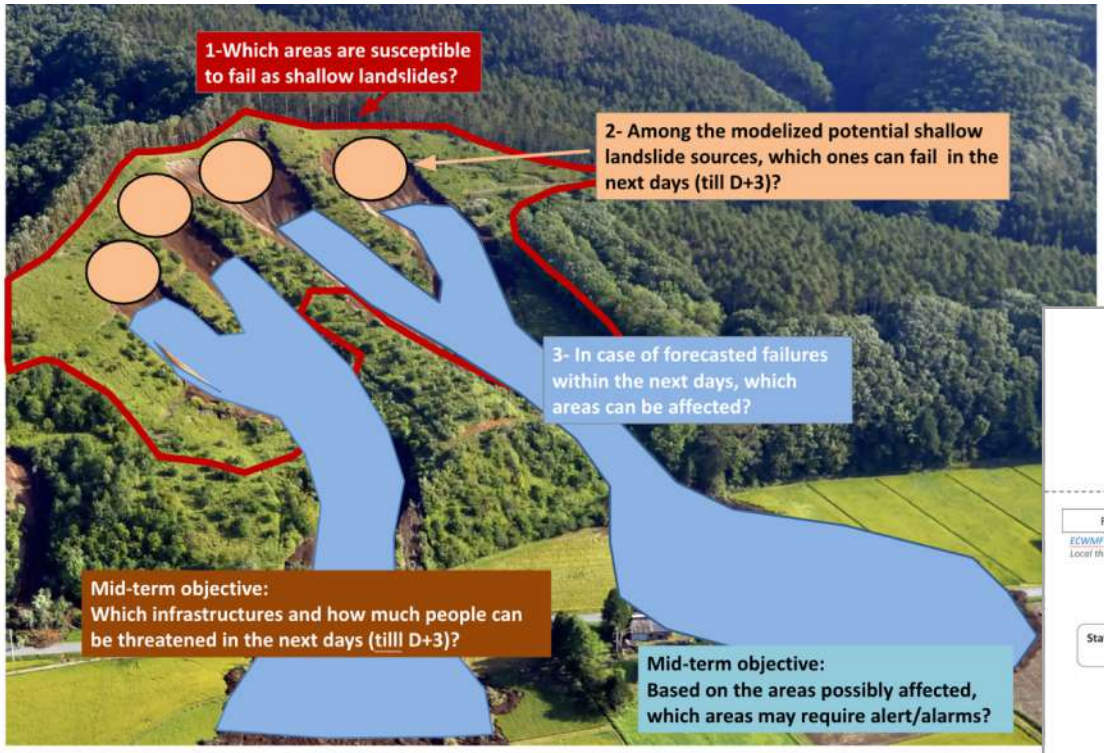
Illustration of the reach angle principle (or Fahrböschung) and of the effect of the maximum velocity parameter (after Horton et al., 2013)

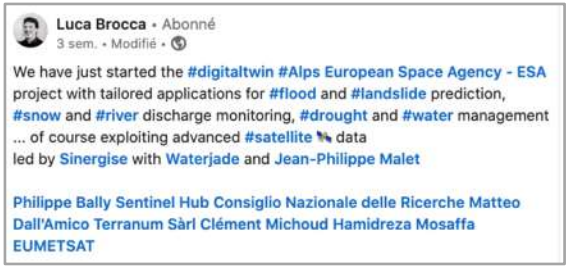
living planet symposium BONN 23–27 May 2022 TAKING THE PULSE OF OUR PLANET FROM SPACE

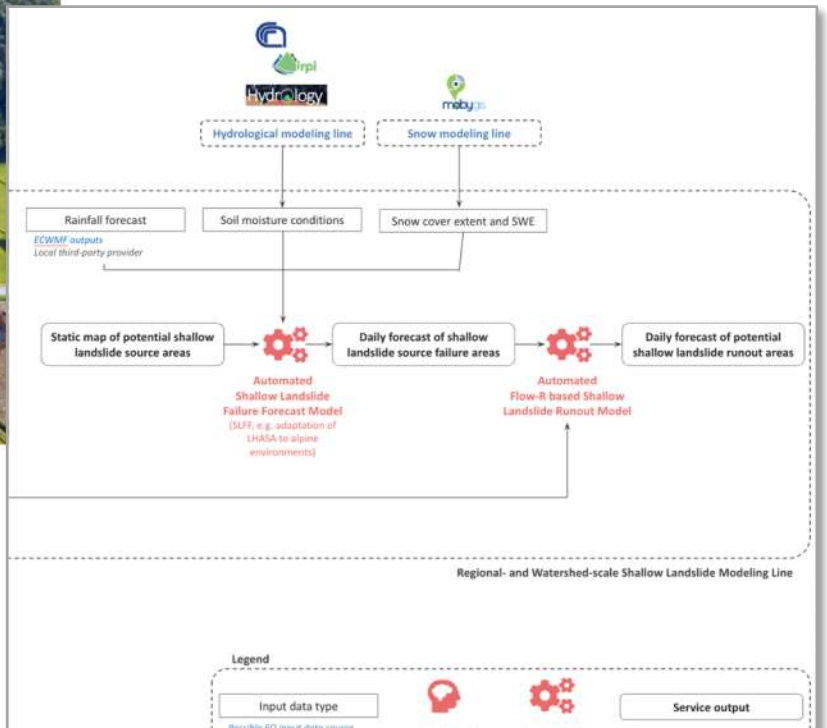
Terranum NASA cnrs

Application #2: Landslide Disaster Risk Products

A demonstrator for the European Alps / DTE-Alps







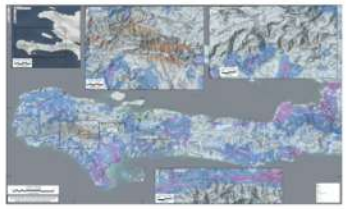
Application #3: Advancing Science with Global Landslide Products

Advancing EO-based landslide inventories for extreme forcing events

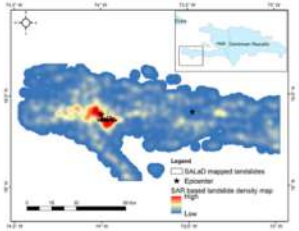
- Science standards for creating and sharing EO-based landslide inventories
- Advance automatic methods to detect landslides
- Benchmarks of datasets and products and On-line repositories to share global landslide data

Landslide inventories mapping on MR/HR imagery

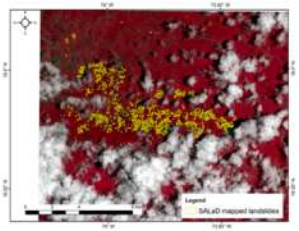
ALADIM vs. HazardMapper vs. SALaD vs. SAR Change



Method: NDVI-based thresholding for landslide detection
Source: Sentinel-2
Credit: BCG Engineering

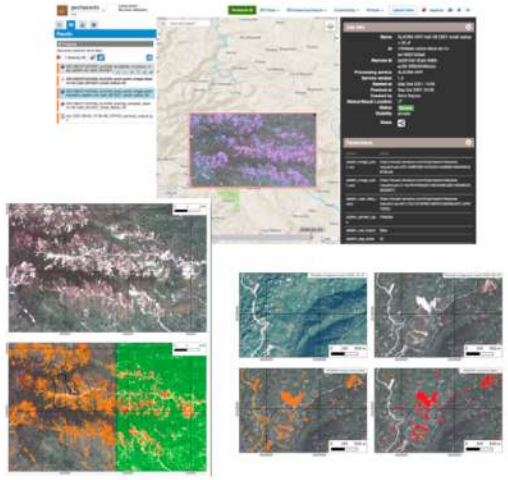


Method: SAR backscatter change landslide proxy density map
Credit: A. Handwerger (JPL) and M.-H. Huang (UMD)
Source: Sentinel-1



Method: SALaD mapped landslides
Credit: P. Amatya (USRA)
Source: Sentinel-2

Method: ALADIM VHR & HR GEP services (bi- and single dates)
Credit: A.Déprez
Source: Sentinel-2 & Pléiades



Team: Pukar Amatya (UMBC/NASA), Jean-Philippe Malet (CNRS-EOST), Aline Déprez (CNRS-EOST), Julien Jean-Baptiste (CNRS-EOST), Corey Scheip (BGC), Alexander Handwerger (JPL), Dalia Kirschbaum (NASA), Stephen Slaughter (USGS), Mong-Han Huang (U Maryland), Robert Emberson (UMBC/NASA), Marin Clark (U Michigan), Dimitrios Zekkos (U Berkeley)

Application #3: Advancing Science with Global Landslide Products

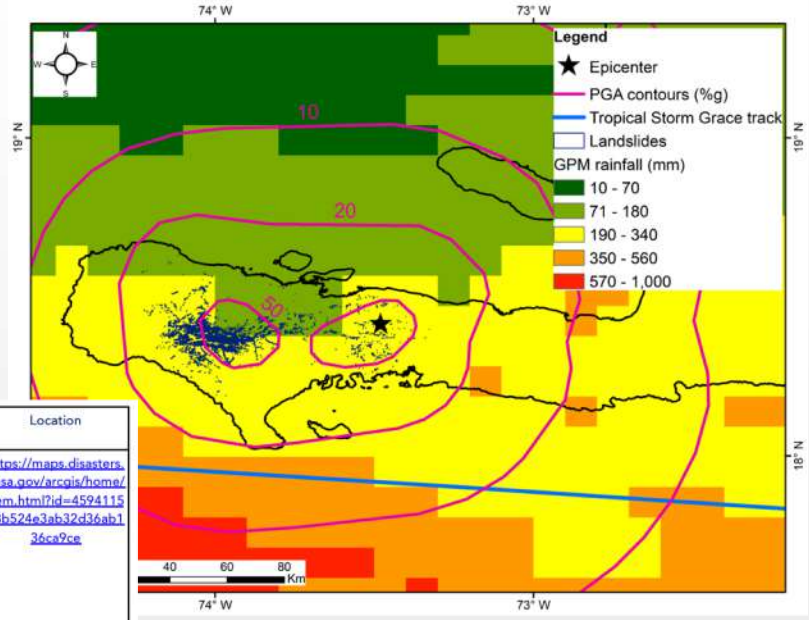
Haiti: August 2021 Earthquake + Tropical Storm Grace

Objectives:

- Document automated landslide rapid response products generated in response to the August 2021 event.
- Quantify accuracy for landslide rapid response products.

Forcing events:

- 4 August 2021: Mw 7.2 earthquake
- 17 August, 2021, Tropical Cyclone Grace



Rapid response products

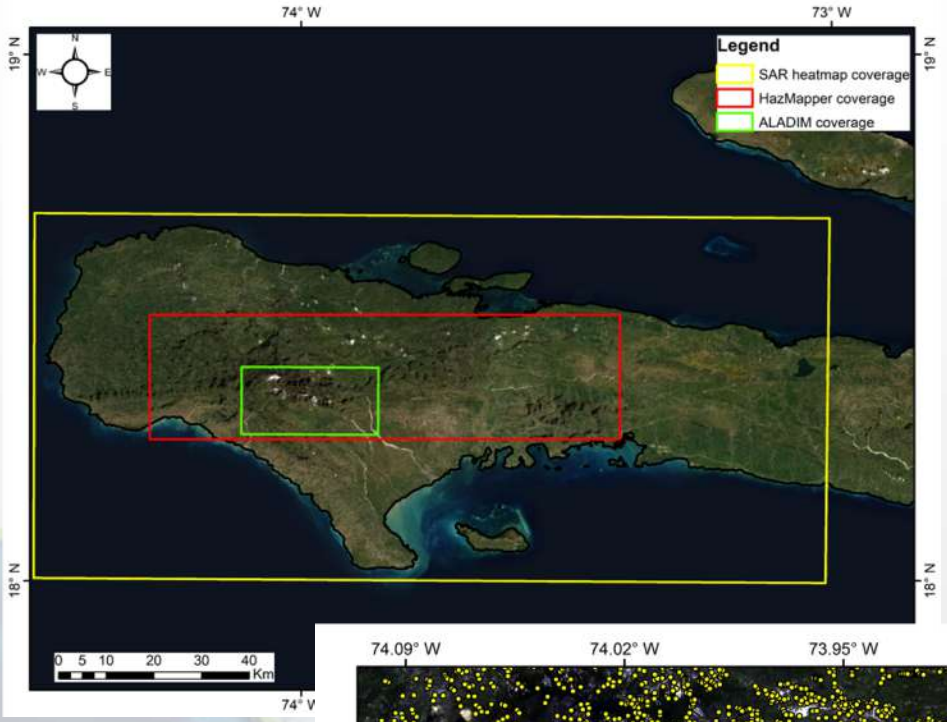
Agency/University/Company	Country	Sensor	Method	Satellite	Date released	Imagery date	Location
NASA	USA	SAR	SAR Backscatter Change	Sentinel-1	August 17, 2021	Pre: August 1, 2017 – August 13, 2021 Post: August 14, 2021 – August 16 2021	https://maps.disasters.nasa.gov/arcgis/home/item.html?id=4594115c3b524e3ab32d36ab136ca9ce
CNRS - EOST	France	Optical	Automated LAndslide Detection and Inventory Mapping (ALADIM)	Pleiades	October 14, 2021	August 23,2021	https://en.poleterresolide.fr/analysis-performed-with-the-aladim-gep-service-to-construct-automated-landslide-inventories-using-pleiades-very-high-resolution-images/
BGC Engineering	Canada/USA	Optical	HazMapper	Sentinel-2	September 3, 2021	Pre: June 12, 2021 – August 12, 2021 Post: August 12, 2021 – August 30, 221	https://disasterscharter.org/web/guest/activations/-/article/flood-large-in-haiti-activation-730-
USGS	USA	Optical	Manual initiation point mapping	MAXAR/Planet/Sentinel-2	December 7, 2021	Various dates according to availability of cloud free image	https://www.sciencebase.gov/catalog/item/61705073d34ea36449a5ed84

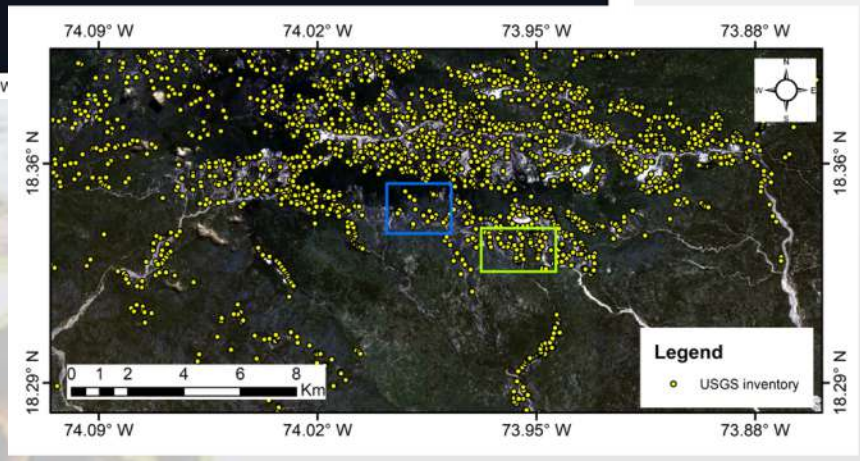
Outcome:

- A paper documenting methodology, accuracy and utility of landslide rapid response products released during this event.

Application #3: Advancing Science with Global Landslide Products

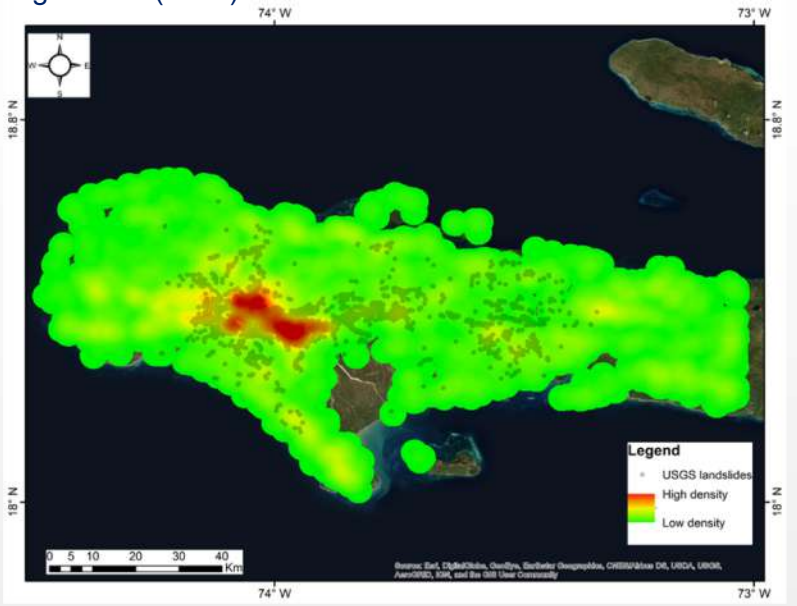
Areal coverage of the rapid response products





SAR backscatter change based heat map (NASA)

Handwerger et al. (2021)



Method: SAR backscatter change heat map
Sensor: Sentinel-1

USGS manually mapped point inventory

(Martinez et al., 2021)

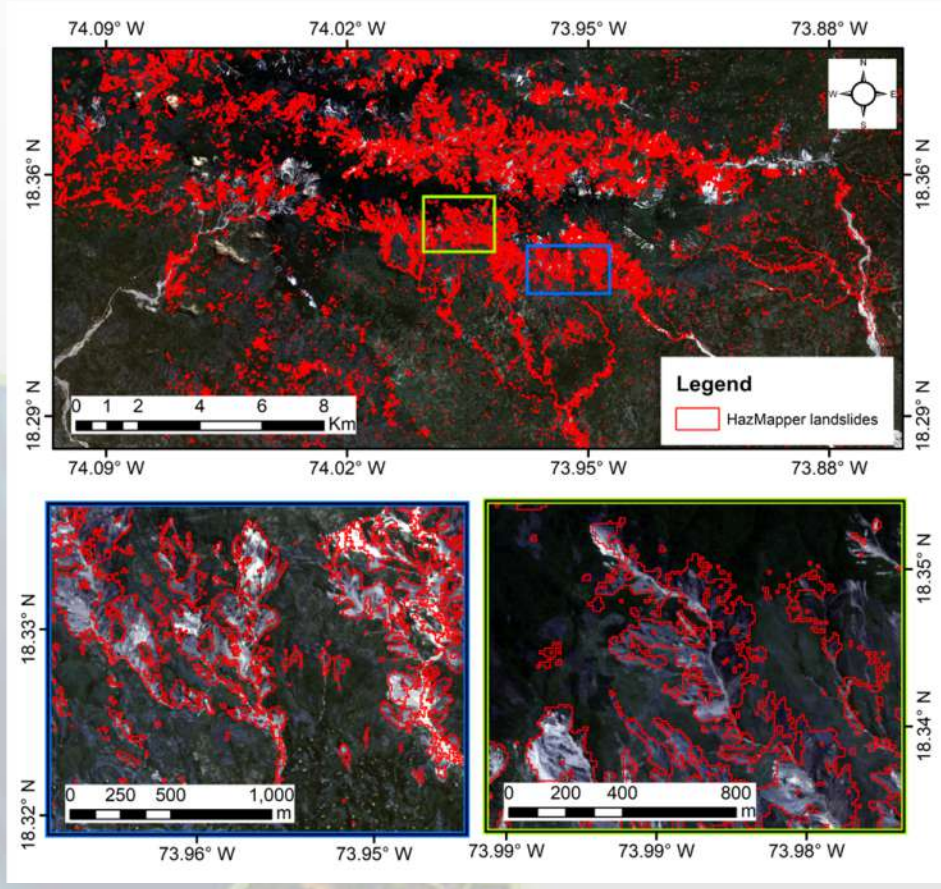
Method: Manual mapping of initiation point
Sensor: Sentinel-2, MAXAR, Planet
Total number: 4893

Application #3: Advancing Science with Global Landslide Products

HazMapper - NDVI difference thresholding

Scheip et al. (2021)

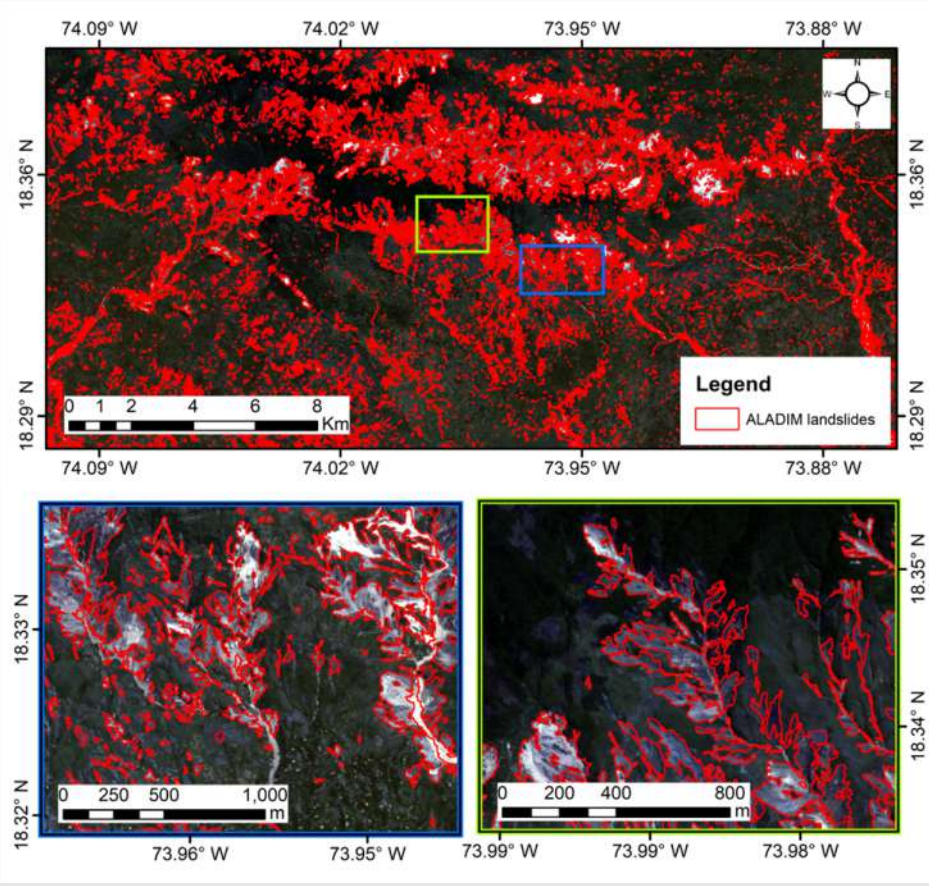
Sensor: Sentinel-2
Total area: 68.27 km^2



ALADIM - Object-based machine learning

Déprez et al. (2021)

Sensor: Pléiades
Total area: 43.93 km^2

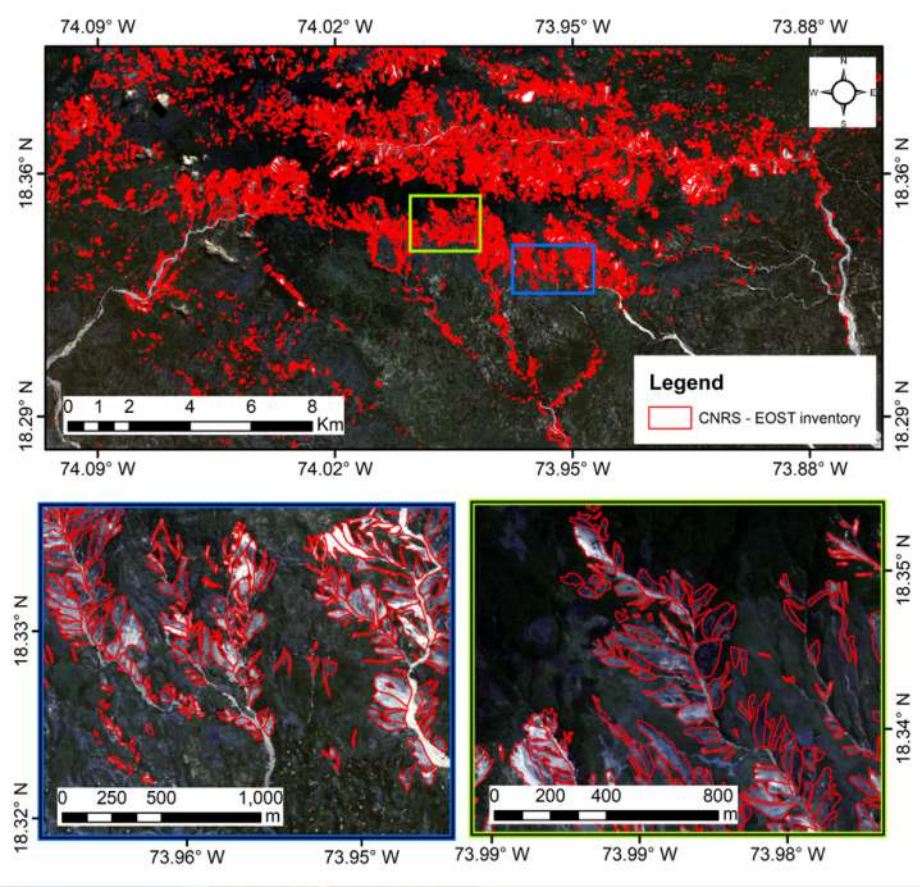


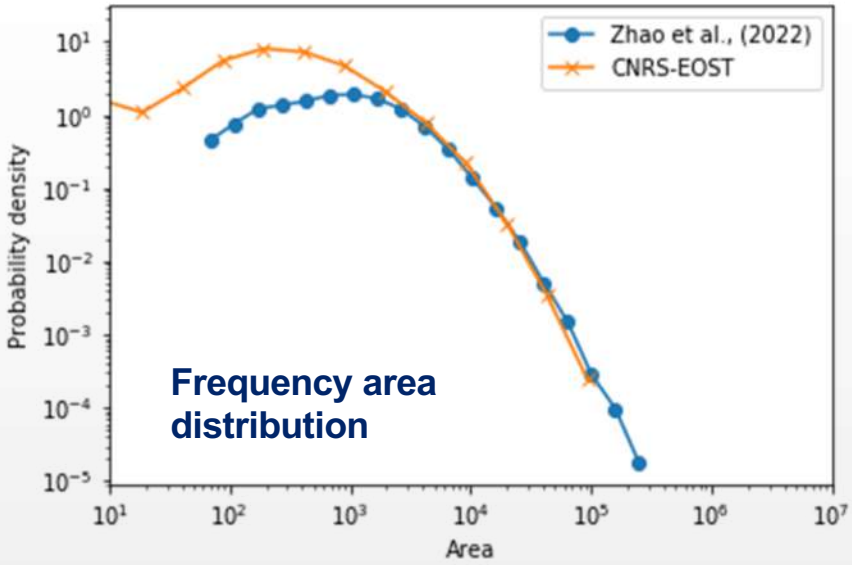
Application #3: Advancing Science with Global Landslide Products

CNRS/EOST manually mapped inventory

Jean-Baptiste et al. (2021)

Sensor: Sentinel-2, MAXAR, Planet
Total number: 14483
Total area: 45.49 km^2





Zhao et al. (2022) manually mapped inventory

Sensor: Google Earth, MAXAR, Planet
Total number: 8444
Total area: 45.8 km^2

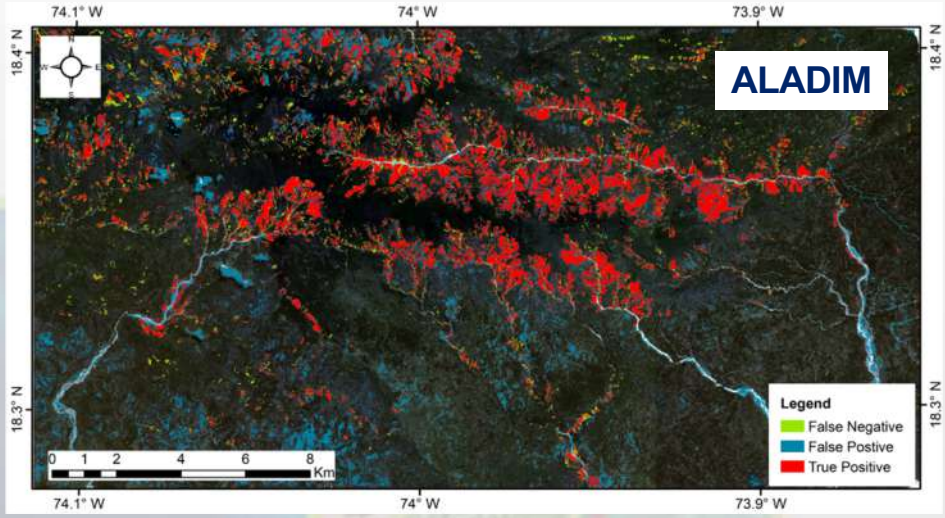
Findings:

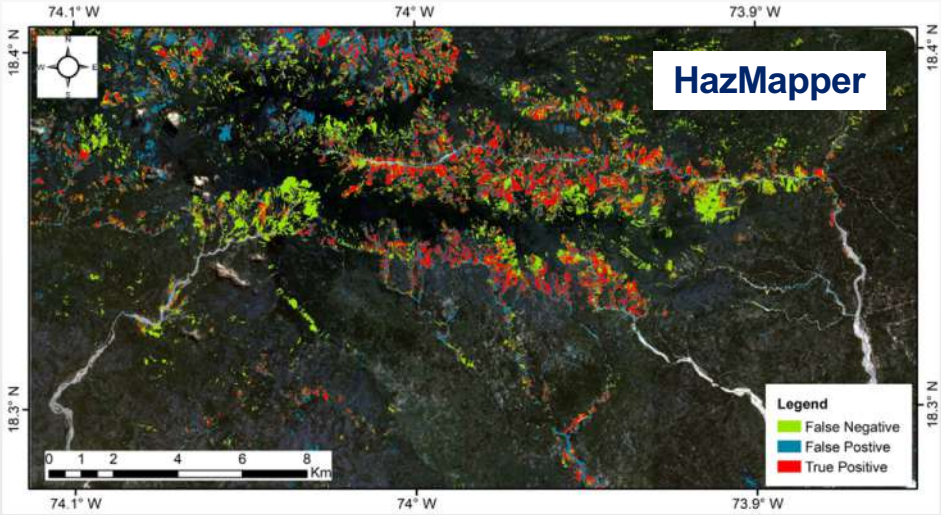
Pléiades VHR and CNRS-EOST inventory captures more smaller landslides than Zhao et al. (2022) inventory.

Application #3: Advancing Science with Global Landslide Products

Validation of automated products using CNRS-EOST reference inventory

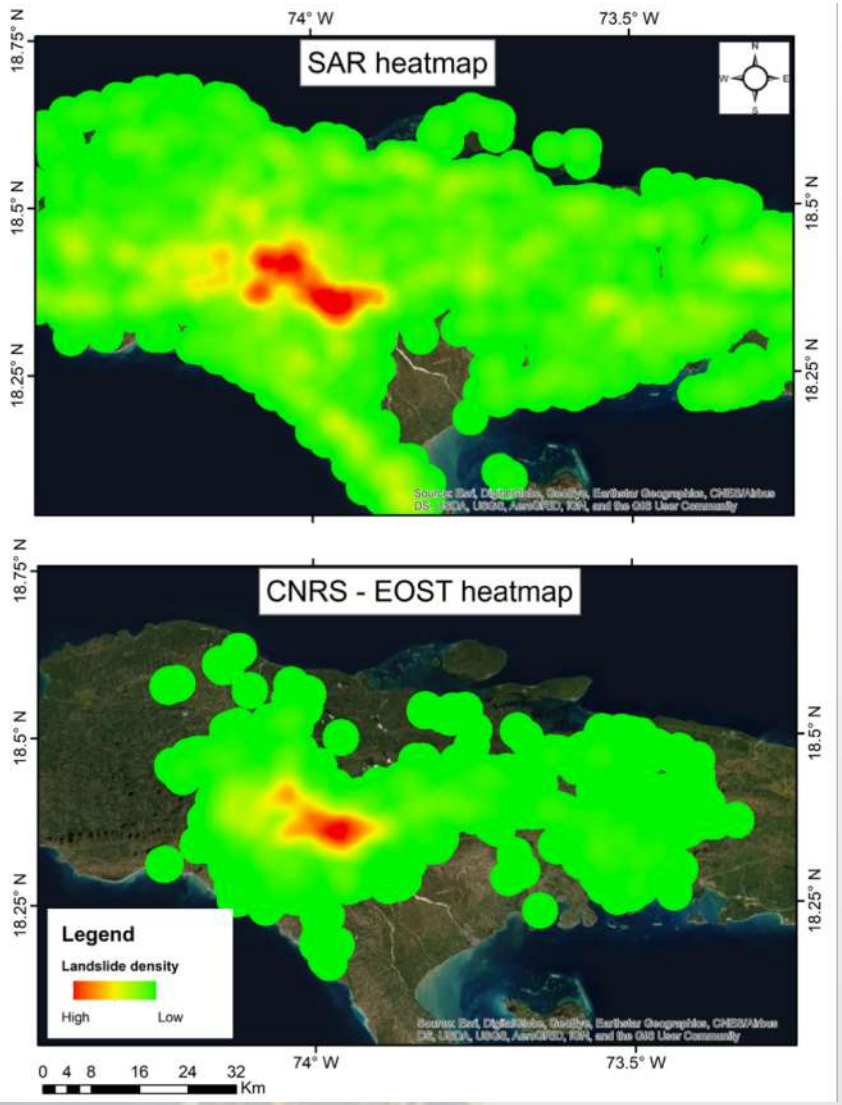
Product	True Positive (m^2)	False Positive (m^2)	False Negative (m^2)	Producer Accuracy (%)	User Accuracy (%)
ALADIM	23093704.39	20916780.26	6956794.62	76.85	52.47
Hazmapper	18601107.70	103813082.82	26871828.73	40.90	27.19
Hazmapper with cloud mask	18601107.70	49788115.03	21816348.93	46.02	27.19





- ALADIM detects most of the landslides.
- HazMapper missed lots of manual landslides, not necessarily because of the method but because of cloud cover in the Sentinel-2 imagery.
- Over Pic Macaya National Park Area, HazMapper has less false detections.

Application #3: Advancing Science with Global Landslide Products

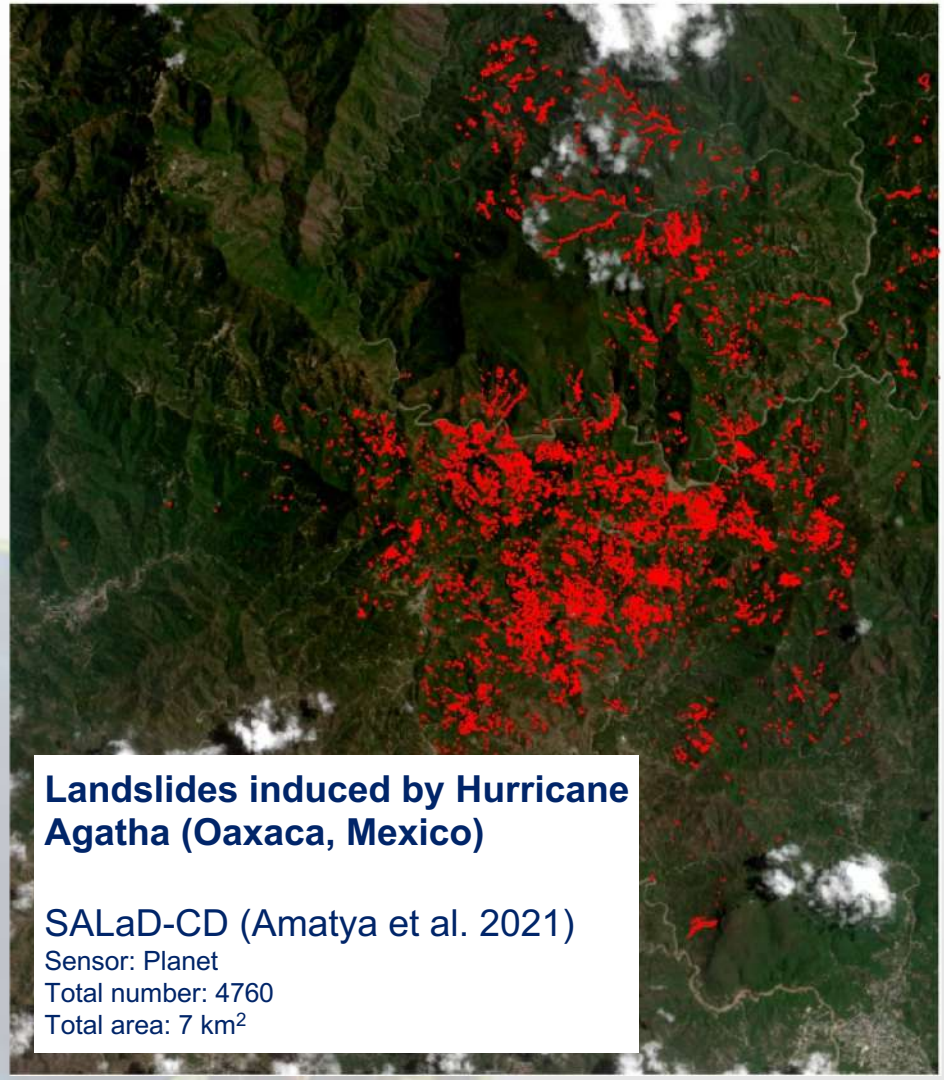


SAR heatmap vs. CNRS-EOST reference heat map

- Accuracy varies between different automated methods.
- Producer Accuracy and User Accuracy of ALADIM was better than that of HazMapper.
- Heat maps can highlight only dense landslide areas such as the Pic Macaya National Park Area for this event.
- Not one best method. All methods compared has its own strength and weakness.
- A paper is being written with submission time frame of end of October 2022.

Application #3: Advancing Science with Global Landslide Products

Other examples

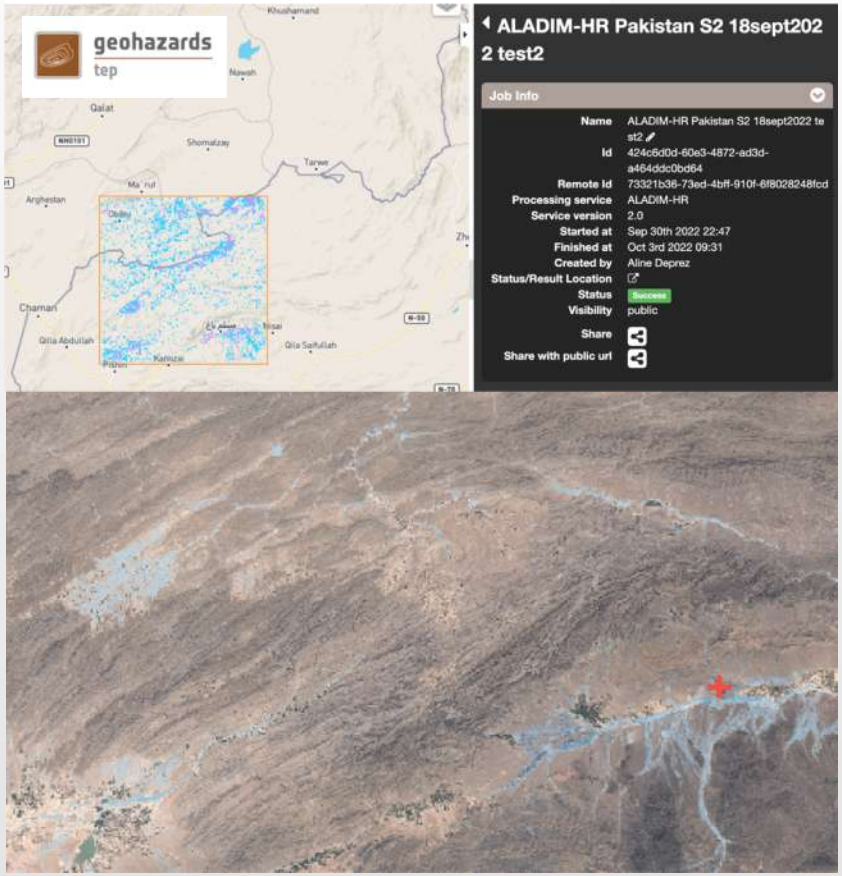


Landslides induced by Hurricane Agatha (Oaxaca, Mexico)

SALaD-CD (Amatya et al. 2021)
Sensor: Planet
Total number: 4760
Total area: 7 km^2

Landslides induced by extreme flooding in Iran / PDNA

ALADIM (Deprez et al. 2022)
Sensor: Sentinel-2
Total area: 350 km^2



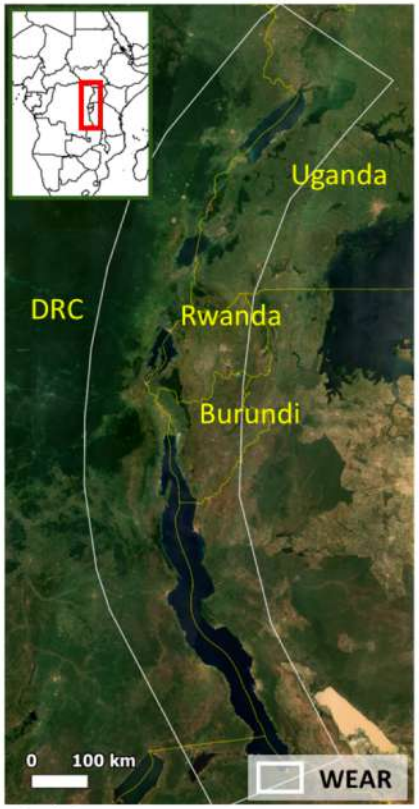
Application #3: Advancing Science with Global Landslide Products

Towards automated methods for large AOIs and landslide location/timing

A. Deijns et al.

GEOTROP — *GEOmorphic hazards and compound events in a changing TROPical East Africa*

VUB Vrije Universiteit Brussel · AFRICA museum · GeoRiskA GeoRisks in Africa · belspo



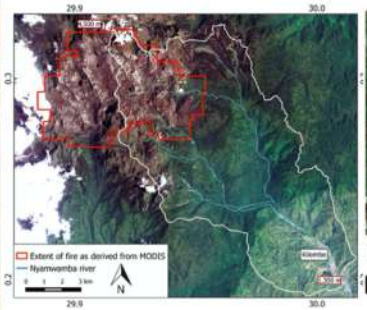
Study Area.

Objective: To assess the role of land transformation and climate change on the occurrence of geomorphic hazards (landslides and flash floods) in tropical East Africa.

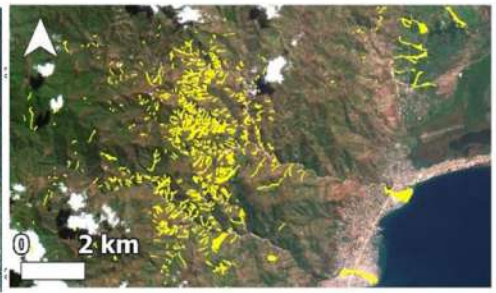
Study area

The western branch of the East African Rift (WEAR) is located in the tropics and characterized by:

- Disproportional impact of GH
- Under-researched in GH
- Expected increase in GH frequency and/or risks in the tropics in response to increasing demographic pressure, climate change and land use/cover changes.



Jacobs et al. (2016), Natural Hazards. Compound forest fire, landslides and flash flood



Deijns et al. (2022) NHESS preprint. compounding landslides and flash flood

Compound Events

The combination of processes (climate drivers and/or hazards) leading to a significant/extreme impact is referred to as a '**compound event**'. Landslides and flash floods frequently co-occur and interact, leading to events with more severe impacts. These events are therefore more accurately analyzed within a compound event framework.

Application #3: Advancing Science with Global Landslide Products

Towards automated methods for large AOIs and landslide location/timing

A. Deijns et al.

GEOTROP

Spatio-temporal detection of GH events
- Current progress-

VUB VRIJE UNIVERSITEIT BRUSSEL · AFRICA museum · GeoRiskA GeoRisks in Africa · belspo

A regional scale problem that needs a regional scale approach

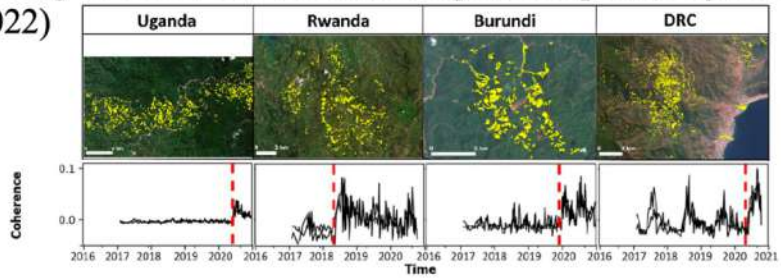
A combination of remote sensing products is required:

- Copernicus Sentinel-1 – *Timing*
- Copernicus Sentinel-2 – *Location*

Properties: *high spatial resolution (10-15m), high repeat time (6/12 days), coverage entire study area, Images from 2015 onwards.*

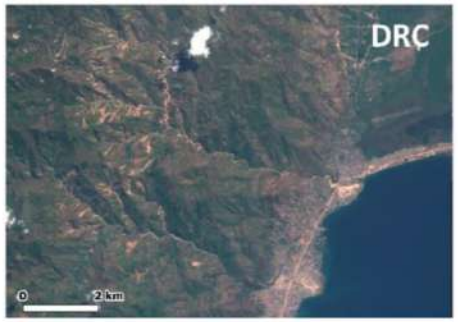
Temporal detection with S1 SAR

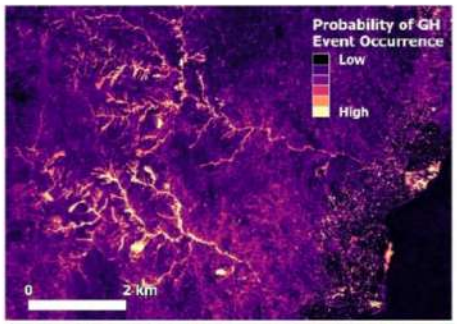
We developed a regionally applicable methodology to detect the timing of GH events in contrasting landscapes. (Deijns et al. 2022)



Spatial detection with S2 multispectral

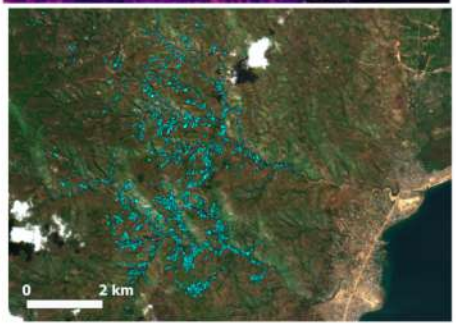
We are developing a tool to regionally explore and detect for GH events. highly optimized in terms of computation time allowing to process large regions of interest





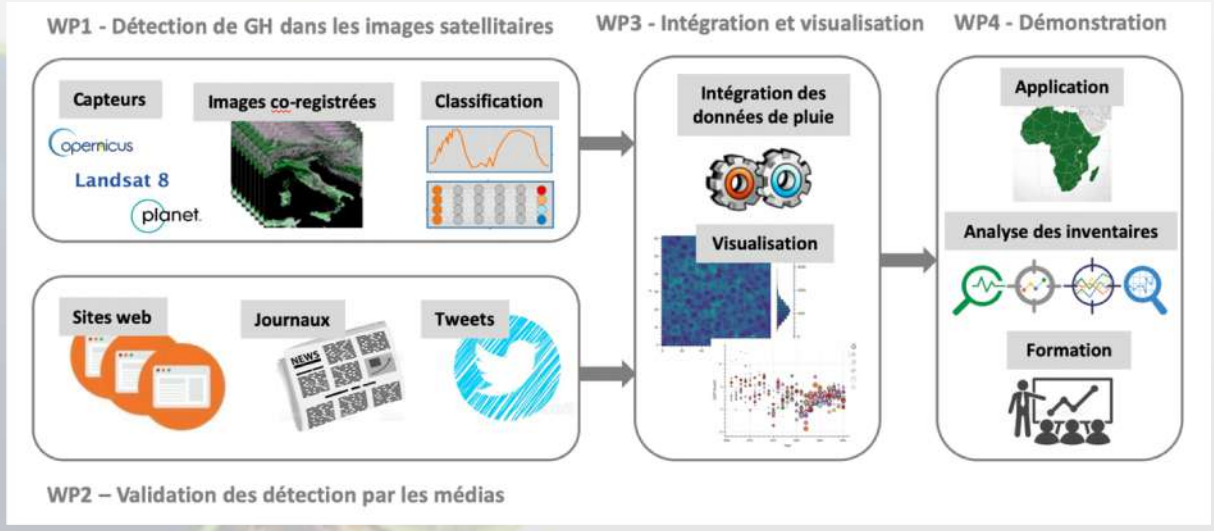
Output of this method can be used as input for robust machine learning based GH detection processors such as ALADIM

Results of ALADIM



Application #3: Advancing Science with Global Landslide Products

The GEOTROP sister project SCO GeoHaTACC: A landslide toolbox for local stakeholders



AFRICA museum

Centre for Research on the Epidemiology of Disasters CRED

Université de Strasbourg