Committee on Earth Observation Satellites

Landslide Demonstrator

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

Working Group Presentation

March 16, 2022

Jean-Philippe Malet, Dalia Kirschbaum, Clément Michoud, Corey Froese, Pukar Amatya, Aline Déprez, Jeanine Engelbrecht, Olivier Dewitte

Landslide Demonstrator Objectives

Demonstrator Leads

Jean-Philippe Malet (CNRS/University of Strasbourg)
Dalia Kirschbaum (NASA)
Corey Froese (BGC Engineering)
Clément Michoud (Terranum)

Landslide demonstrator focuses on three key areas in which landslide hazard/risk assessment may be advanced using a combination of EO data and models to support different end-user communities.

- **Application 1**: Use satellite data for landslide disaster assessment and mitigation along **transportation and pipeline corridors**, with goal of establishing local monitoring of areas of possible danger with consistency of observation, and of facilitating the assessment of the future evolution of these slopes
- **Application 2:** Use of satellite data for establishing **landslide risk financing products** (country or region risk profiles, hazard and risk maps) in full complementarity with the World Bank Disaster Risk Financing and Insurance Program (DRFIP).
- **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 intense rainfall and/or high magnitude earthquakes in terms of standardized inventories of different complexity.

Demonstrator Timeline

Demonstrator Implementation Plan – Start Date: June 2021

- **Year 1 (June 2021 – June 2022):**
  - Definition of landslide services and products requirements for the three applications.
  - EO-satellite database creation for the geographical use cases.
  - Consolidation of resources (persons, data, IT processing).

- **Year 2 (June 2022 – June 2022):**
  - Demonstration of the landslide services for some use cases and reporting;
  - Concept of the prototype demonstration App on GEP for the three applications.

- **Year 3 (June 2023 – June 2024):**
  - Implementation of the prototype demonstration App on GEP for the three applications;
  - Training and dissemination on-line user-oriented material for the three applications.
  - Final Demonstrator reporting

Data procurements: status

- **CSA** (Canada): **RCM data** (5 m Strip Map) over Swan Hills

Collection started End July 2020 – on-going (acquisition each 4 days)

- **DLR** (Germany): **TSX SpotLight** tasking over 2 sites (1 Canada, 1 France) for 2 years time series (140 images per sites)

Data acquisition started over Drynoch (Canada), start in October for La Valette/Ubaye (France)

- **CNES** (France): **Stereo/Tri-stereo Pléiades** tasking over 3 sites for time series

Request send to CNES early September (6500 km^2 / year - for 2 years)

- **Conae / ASI**: **SAOCOM** for 2 years over 2 sites

For Canada, agreement pending with Conae ; For France – request to ASI in preparation (April 2022)

- **ASI**: **CSK** tasking for 2 years for 1 site

For Swiss/Italy - request to ASI in preparation (April 2022)

Application 1: Transportation Corridors

Application 1: A demonstrator for the operational landslide monitoring of traffic and pipeline corridors (China, European Alps, Canada)

Demonstrator Leads: Jean-Philippe Malet (CNRS/EOST) and Corey Froese (BGC)

Industry Participants: Highway/Train companies, Pipeline companies, Engineering Geology Bureaux, State offices

Pipelines to be protected

Methodologies

- Use of InSAR-PSI techniques to monitor slow-moving deformation patterns
- Use of optical derived techniques to monitor fast-moving deformation patterns
- Definition of procedures to propose permanent monitoring services over the uses cases as demonstrator

East France – March 2020 – landslide on high speed train TGV

Elkhorn city (Kentucky, US) – February 2020 – shallow landslide / mudflow

Swan Hills – Preliminary results

The Swan Hills area in northwestern Alberta Province, Canada has known susceptibility to widespread, deep-seated land sliding, affecting infrastructure, utilities and transportation corridors

A dedicated slope hazard assessment program has been initiated to develop hazard management frameworks. Monitoring data includes:

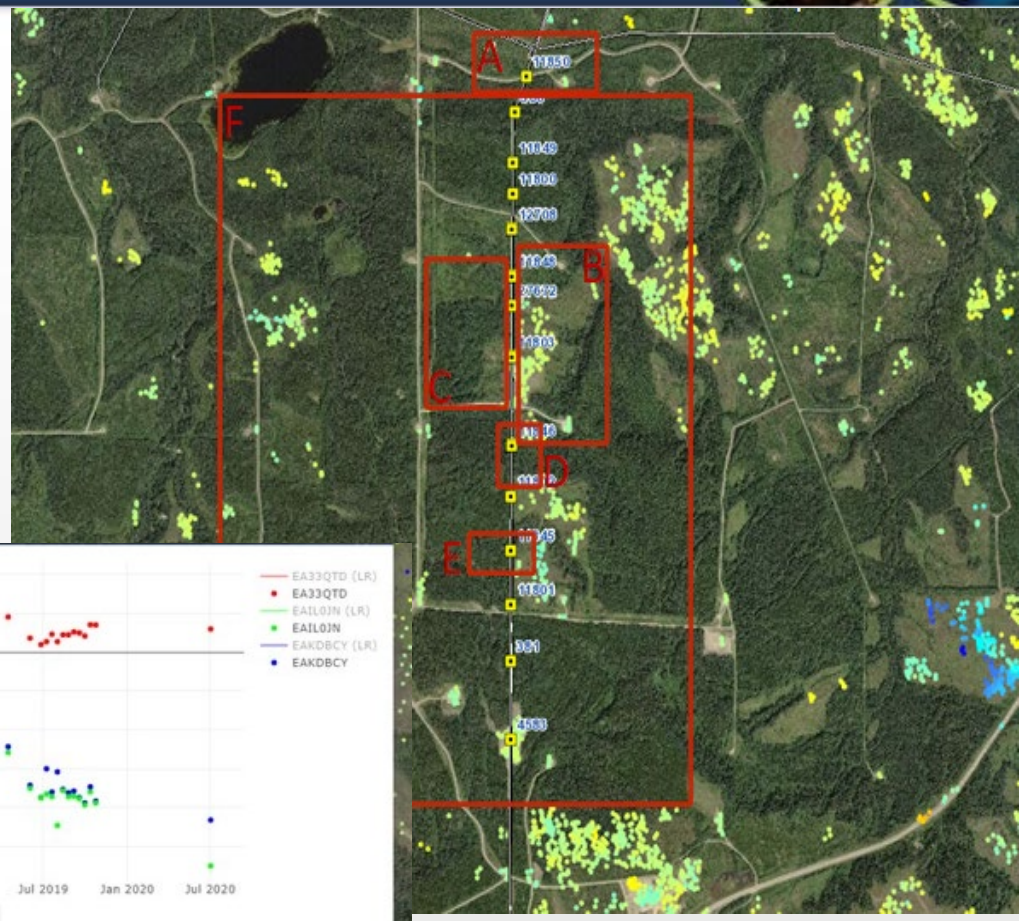
- LiDAR and LiDAR change detection (LCD)
- Instrumentation (slope inclinometers, shape acceleration arrays and vibrating wire piezometers)
- Satellite EO : RCM and SAOCOM data

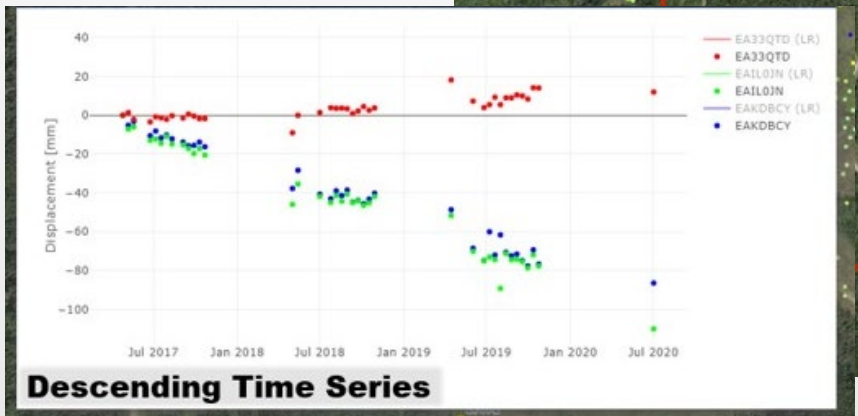
Swan Hills – Preliminary results

Preliminary stage:

Sentinel-1 data was analyzed
Vegetated area - Monitoring points are sparse with C-band data at 20 m resolution and 12-day revisit

Potential to increase the InSAR coverage by using higher resolution Radarsat Constellation Mission data (RCM) with 4-day revisit, or longer wavelength SAOCOM (L-band) data



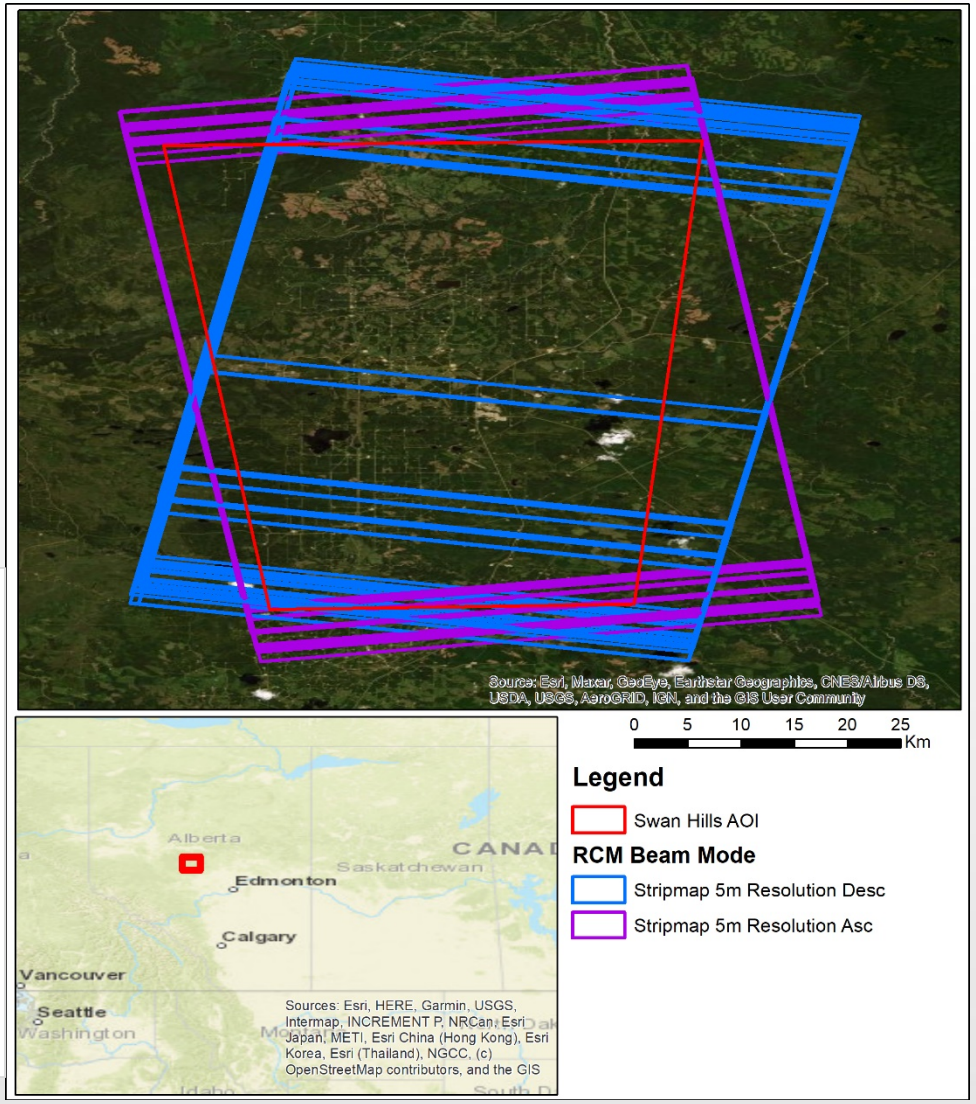


Swan Hills – RCM data

Radarsat Constellation Mission (RCM) – 5 m Stripmap mode data in Ascending and Descending mode have been acquired

Captured roughly every 4 days from 2020-07-24 and acquisitions are ongoing

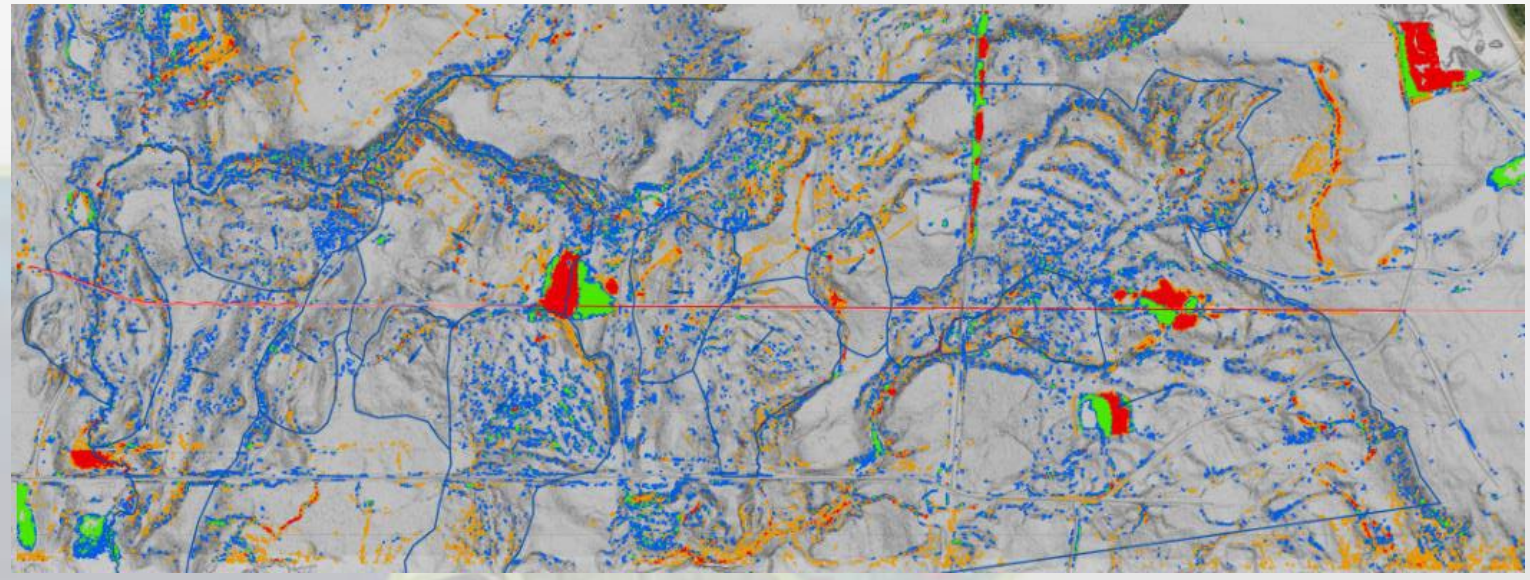
Analysis focused on snow-free periods



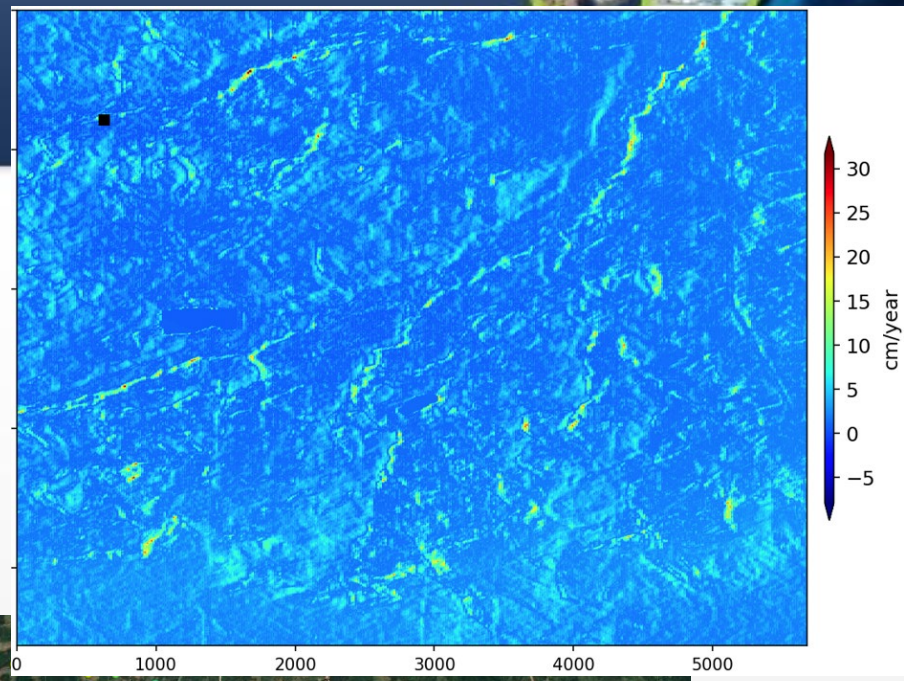
Swan Hills – RCM progress

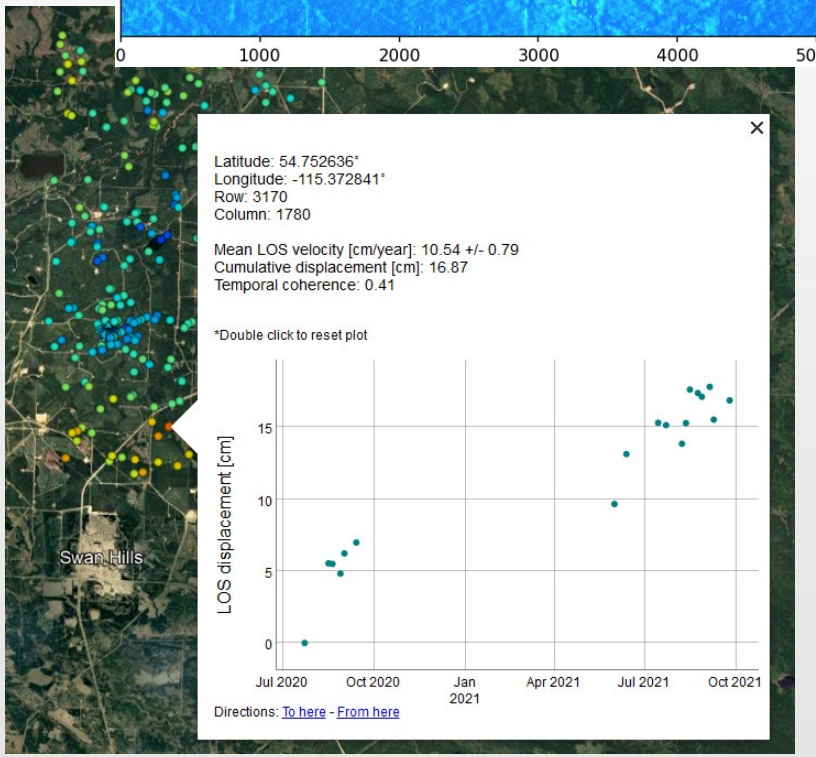
LiDAR change detection data have been acquired for comparison

RCM data processing and timeseries optimization is ongoing



LiDAR Change detection results





Transportation Corridors: OTELO Consortium

OTELO

Outils de TELédétection opérationelle des mOuvements de terrain

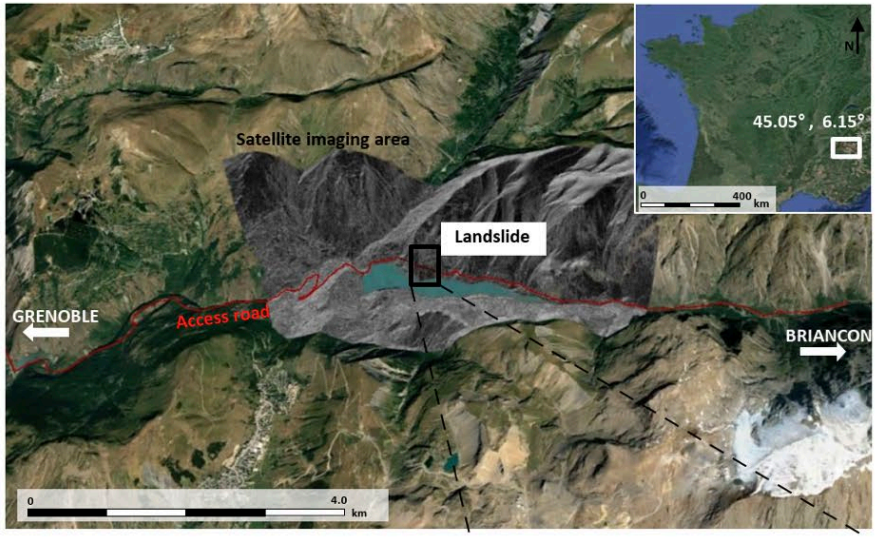
Aménagement en montagne : connaissance de la montagne et effets du réchauffement climatique, sécurisation des sites et infrastructures

Défi proposé par la Région Auvergne Rhône-Alpes

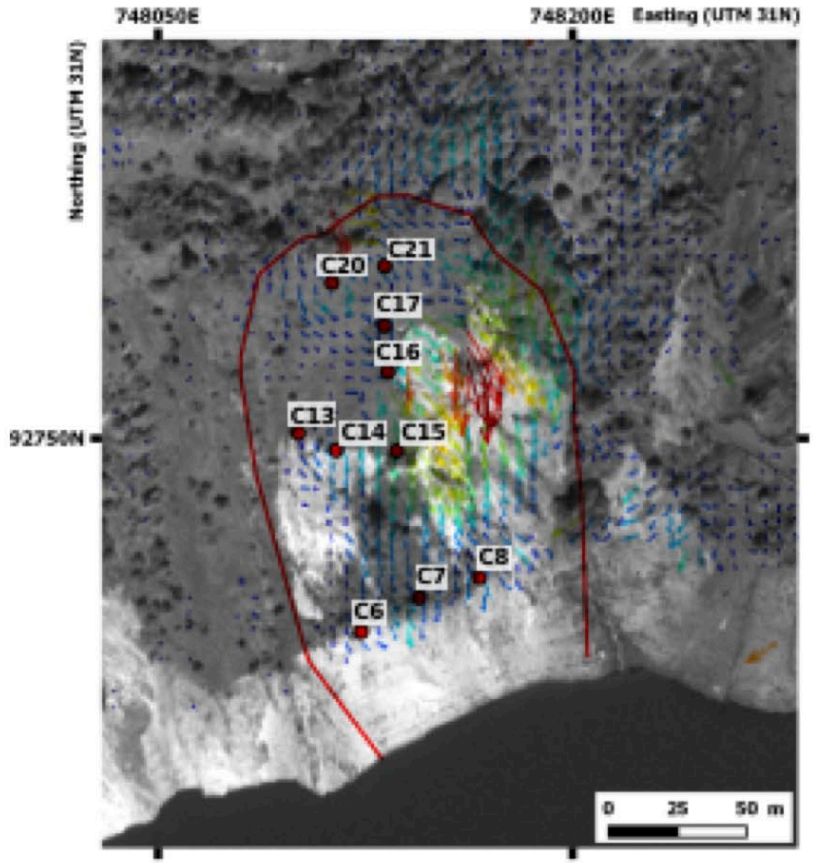
Transportation Corridors: OTELO Consortium

OTELO

- développement d'un portfolio de produits spécifiques au suivi de versants instables
- Des produits multi-résolution, multi-capteurs et multi-techniques (InSAR, corrélation d'images)



Champ de déplacement issu de la corrélation d'images Sentinel-2



Satellite Pre-Failure Detection and In Situ Monitoring of the Landslide of the Tunnel du Chambon, French Alps (Desrues et al., Geosciences 2019)

Transportation Corridors: OTELO Consortium

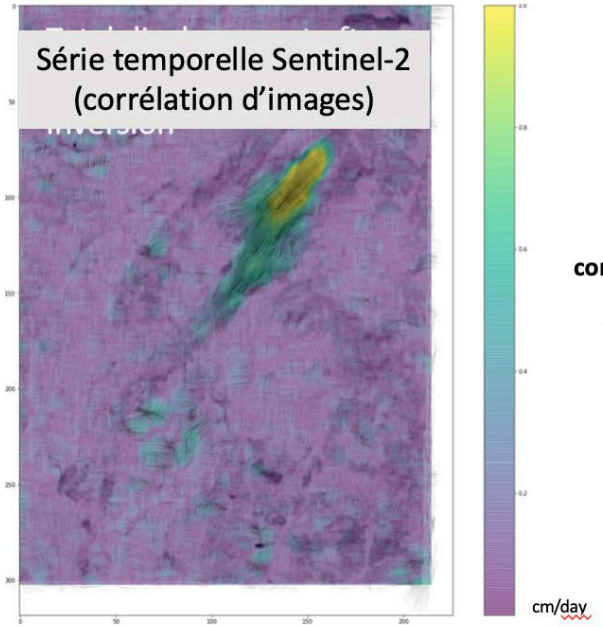
Images satellite multi-spectrales / optiques

- 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)



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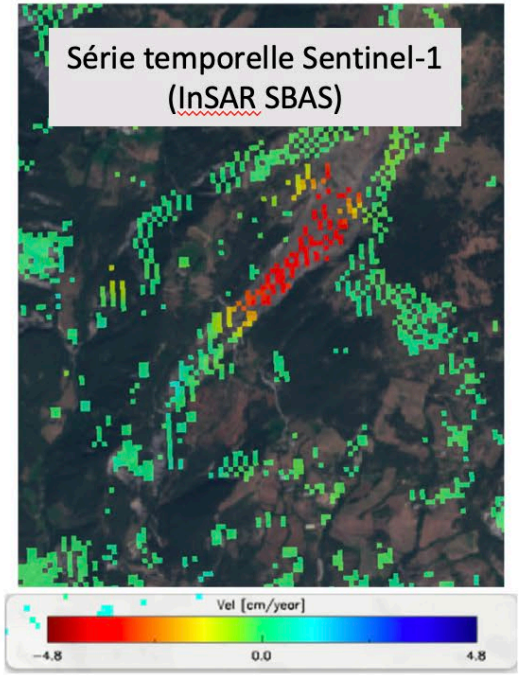
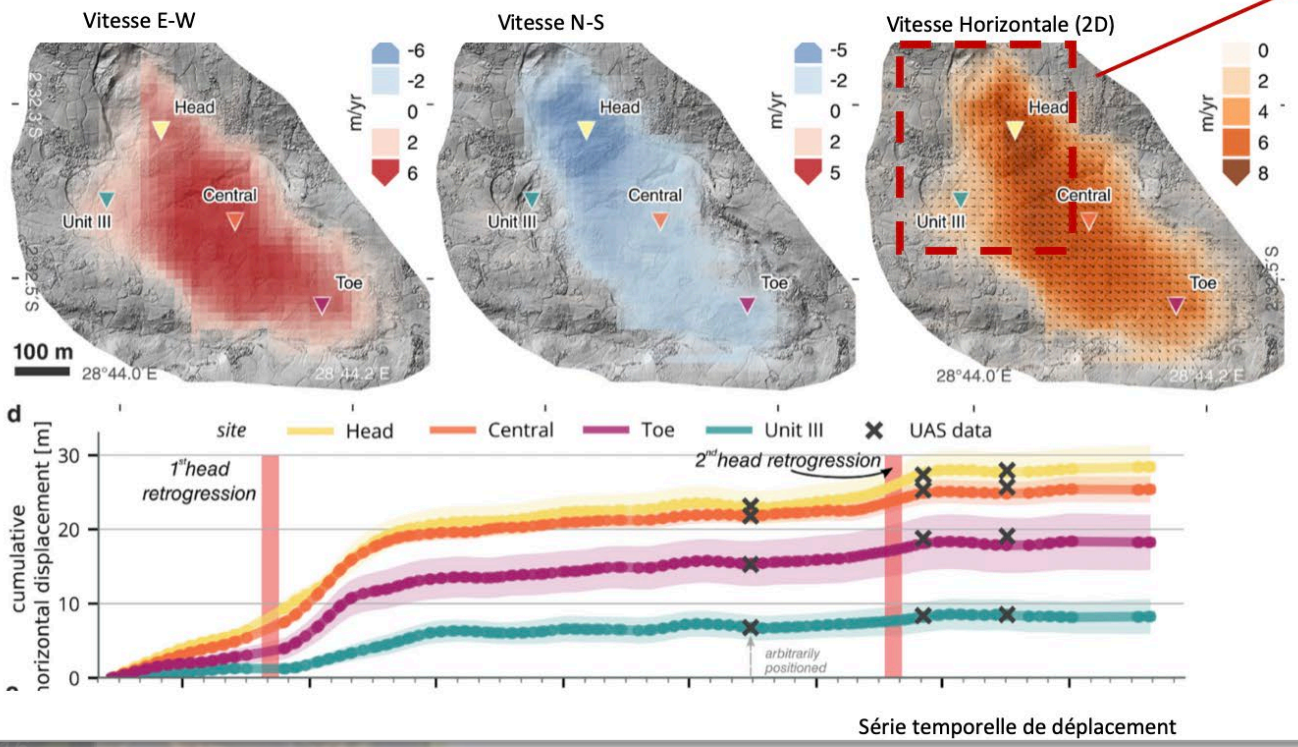


Transportation Corridors: OTELO Consortium

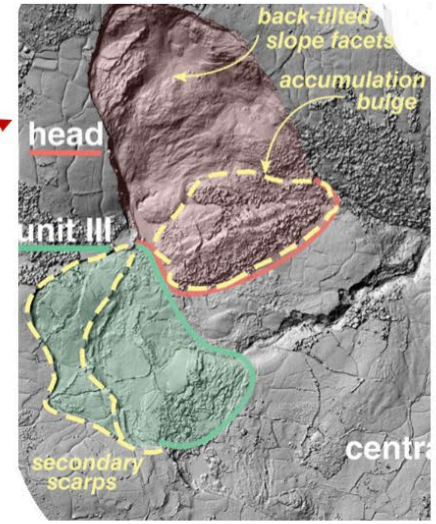
Un portfolio de produits complémentaires pour une vision synthétique du territoire

Produit du Lot 2 : suivre les mouvements de terrain « lents » et « rapides » à partir d'images radar en synthèse d'ouverture (SAR)

(Sentinel-1, Cosmo-Skymed, TSX/PAZ, et futur NiSAR)



Série temporelle de déplacement



Cartes et séries temporelles de champs de déplacement / vitesse
En radar : 365 jours / an

Transportation Corridors: OTELO Consortium

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

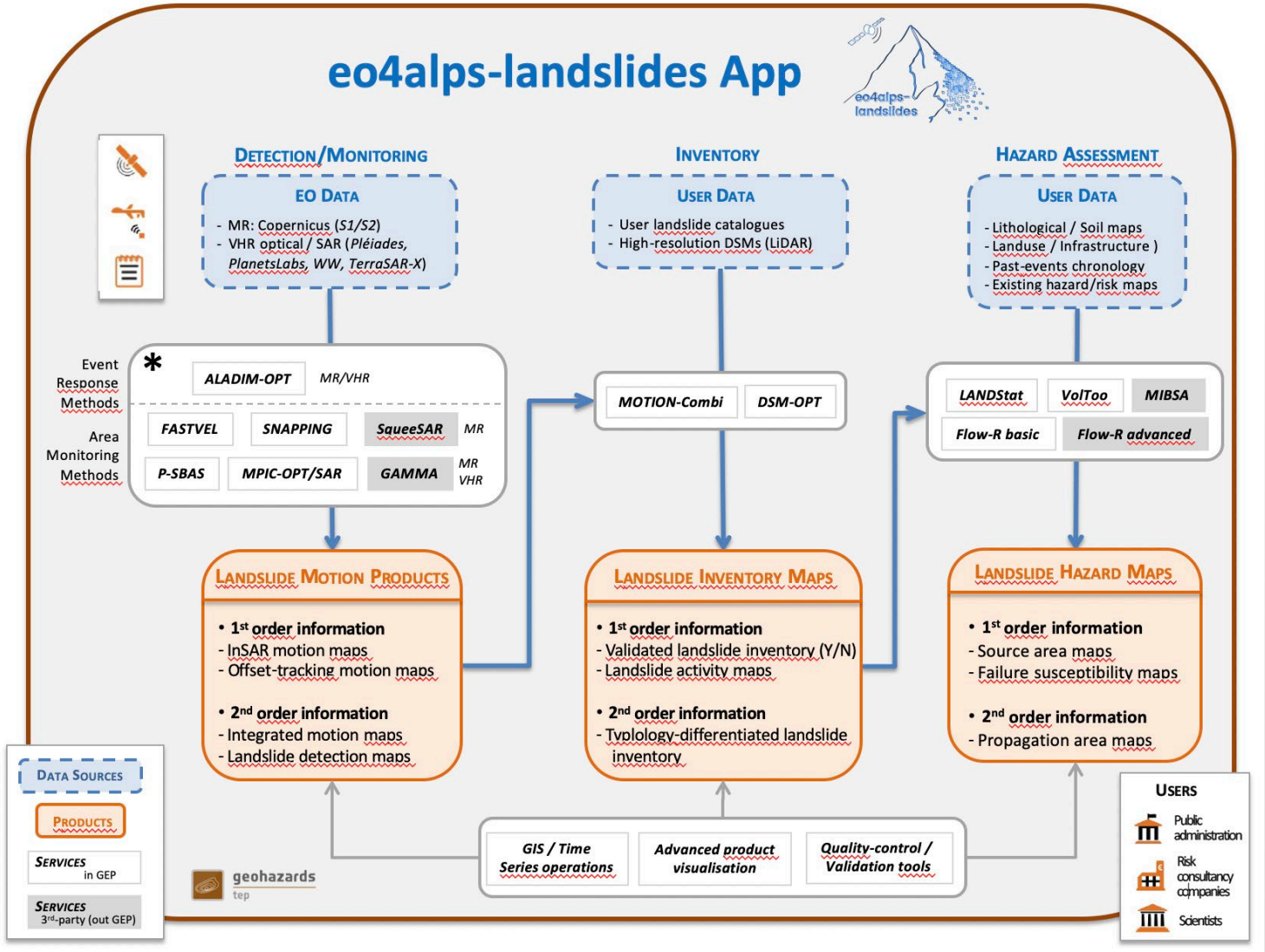
Modèle économique

Env. 25 lots / an (> 2023)
Coût du lot défini en nombre d'images et superficie de la zone d'intérêt

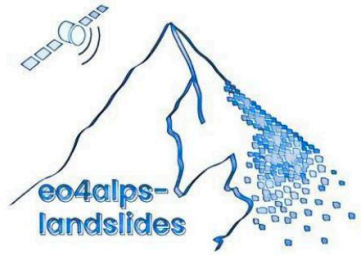
Suivi annuel : volume de prestation estimée à environ 50 k€/an

Nouveaux marchés

In Q3 2022: an operational system for landslide monitoring/hazard modelling for the Alps



www.eo4alps-landslides.eu



esa
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).

>> 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	✗	✗	✗	✓

LOCAL SCALE ANALYSIS									
Type	**Scope**	**SNAPPING**	**P-SBAS**	**FASTVEL**	**SqueeSAR**	**GAMMA**	**ALADIM**	**MPIC**	**DSM-OPT**
Ground motion services	Landslide monitoring	✓	✓	✓	✓	✓	✗	✓	✓

Type	**Scope**	**VOLTOO**	**FLOW-R**	**MIBSA**	
Hazard modeling services	Landslide modeling	✓	✓	✓	

www.eo4alps-landslides.eu

Ground Motion Service: SNAPPING – Surface motioN mAPPING

Input data: Sentinel-1 Level 1 SLC

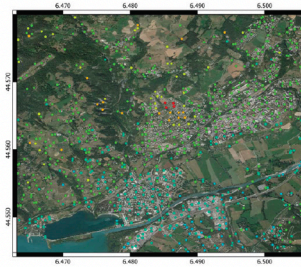
SNAPPING
SURFACE MOTION MAPPING

Service owner: Aristotle University of Thes

Service support: snapping@eo4alps-landsl

Use case 1: Alpine shallow continuously m

In this use case the hillslope is affected landslide for more than 30 years, and a sliding velocity is observed for the la man-made structures are heavily affect SNAPPING service was used to proces images from ascending and descending tra



Ground velocities in the LoS direction c SNAPPING-MR (Medium Resolution) j 2015-2020.

Ground Motion Service: SqueeSAR®

Input data: Sentinel-1, TerraSAR-X, PAZ, CSK, CSG, Radarsat-2, Radarsat-1, ALOS1, ALOS2, ERS, ENVISAT

SqueeSAR®
TRE ALTAMIRA

Description:
SqueeSAR® is an InSAR processor capable of extracting reliable information possible from SAR images by exploiting point-wise Permanent Scatterers (PS) and Distributed Scatterers (DS). Developed from the original PSInSAR™ technology, SqueeSAR® applies to small scale areas, regional and national level areas.

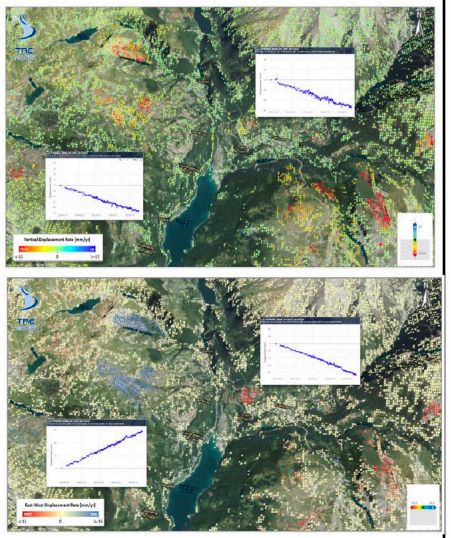
Service owner: TRE ALTAMIRA

Service support: squeesar@eo4alps-landslides.eu

Use case 1: Valle de Tena, Pyrenees, Spain

Large, deep seated flow-dominated and complex movements in altered and tectonized Palezoic slates constitute 80% of landslides in the upper part of Valle de Tena (Gállego River, central Spanish Pyrenees). The toe and flanks of the landslides are often affected by secondary failures induced by fluvial erosion.
The objective of the analysis is to monitor ground movement during the period November 2014 - July 2019 in order to document the impact of climate change in the Pyrenees. The study consisted of processing 202 Sentinel-1 radar images in ascending orbit in the period 12/11/2014 - 07/31/2019, and 205 images in the period 10/30/2014 - 12 / 07/2019 in descending orbit.
The trigonometric combination of the SqueeSAR® results obtained from two orbits (i.e. ascending and descending), produces 2-D (vertical and horizontal in East-West) measurements of ground motion. Thanks to the high density obtained in both Line-of-Sight (LoS) ascending and descending geometries, the 2D decomposition showed high density of information in the Vertical and East-West dimensions. Velocities in the range of 1-2 mm.yr^{-1} are detected as well as acceleration/deceleration phases in the displacement time series.

Ground velocities in the Vertical (Top figure) *and East-West* (Bottom figure) *directions computed over the Upper part of Valle de Tena (central Spanish Pyrenees), obtained from the 2D-decomposition of the LOS SqueeSAR® measurements for the period November 2014 to July 2019.*



Ground Motion Service: MPIC-OPT-SLIDE

Input data: Copernicus Sentinel-2 (10m resolution)

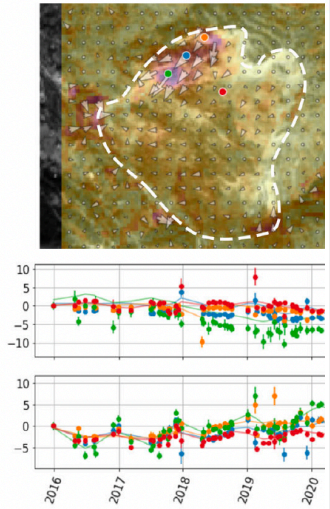
Description: This service is designed to compute landslide

MPIC-OPT SLIDE

Service owner: CNRS – École et Observatc

Service support: mpic@eo4alps-landslide

Use case 1: La Clapière, French Alps, Fr
On-line public results: Here



Modeling Service: Flow-R

Input data:
Mandatory: location of landslide source areas
Subsidiary: local third-party DEM

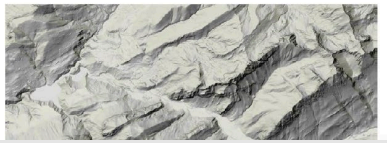
Description: Flow-R is a software for rapid and reliable modeling of gravitational hazards. It allows assessment of the propagation area based on several published empirical run-out models at local and regional scales.

Service owner: Flow-R is owned, developed and maintained by Terranum Sàrl (Switzerland).

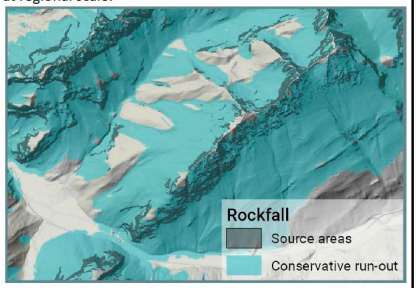
Service support: flow-r@eo4alps-landslides.eu

Use case 1: Debris-flow and rockfall regional susceptibility maps, Swiss canton of Fribourg
On-line public results: Here

The public authorities of the alpine canton of Fribourg, in Switzerland, require both debris-flow and rockfall susceptibility maps for its entire territory (1700 km²) in order to identify inhabited areas, infrastructure and communication networks potentially threatened by these natural hazards. Since this study aims to prioritize sectors that will need detailed but costly studies, it has to be based on simple, robust and affordable numerical models. Therefore, once potential rockfall and debris-flow source areas are located using empirical geomorphological GIS-based criteria, the Flow-R service computes run-out areas.
For this study, both Flow-R_basic (on GEP) and Flow-R_advanced were used. Indeed, the Flow-R_basic service uses predefined parameter sets for several hazard types calibrated for Alpine extreme events, leading to conservative propagation extents. The rockfall susceptibility map is modeled by "Flow-R on GEP". Then, the debris flow susceptibility map required different scenarios, from conservative to current models. Terranum, as service provider and developer of Flow-R, offers on-demand tailored processing in the Flow-R_advanced service..
Flow-R_basic uses the EEA-10 m DSM and a user-provided source areas as input files. Parameter sets for the different hazard types are predefined using model calibrations for extreme events in the Alps.



The rockfall susceptibility map, run in GEP, therefore leads to conservative propagation extents appropriated for this study at regional scale:



Extent of conservative rockfall runout areas, modeled by the Flow-R_basic service.

With the Flow-R_advanced support, the debris-flow susceptibility map is calibrated to the local setting. Moreover, the advanced susceptibility map distinguishes different reach susceptibility levels: from low for extreme events to very high for current/frequent debris-flows.

Application 2: Landslide Risk Financing

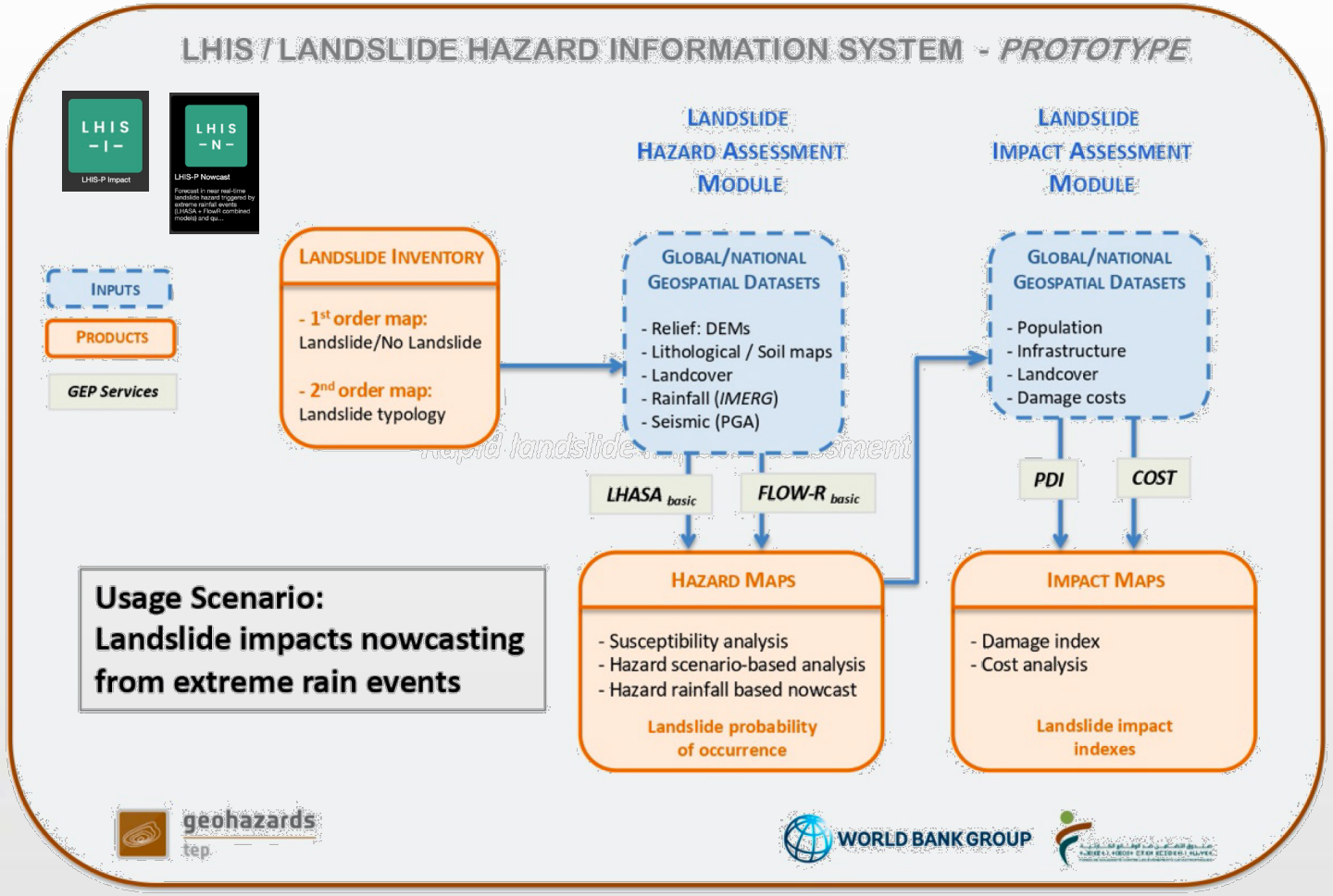
Application 2: Operational Landslide EO Products for Disaster Risk Financing and Insurance Program (World Bank)

Demonstrator Leads: Clément Michoud (Terranum) and Jean-Philippe Malet (CNRS)

Industry Participant: World Bank

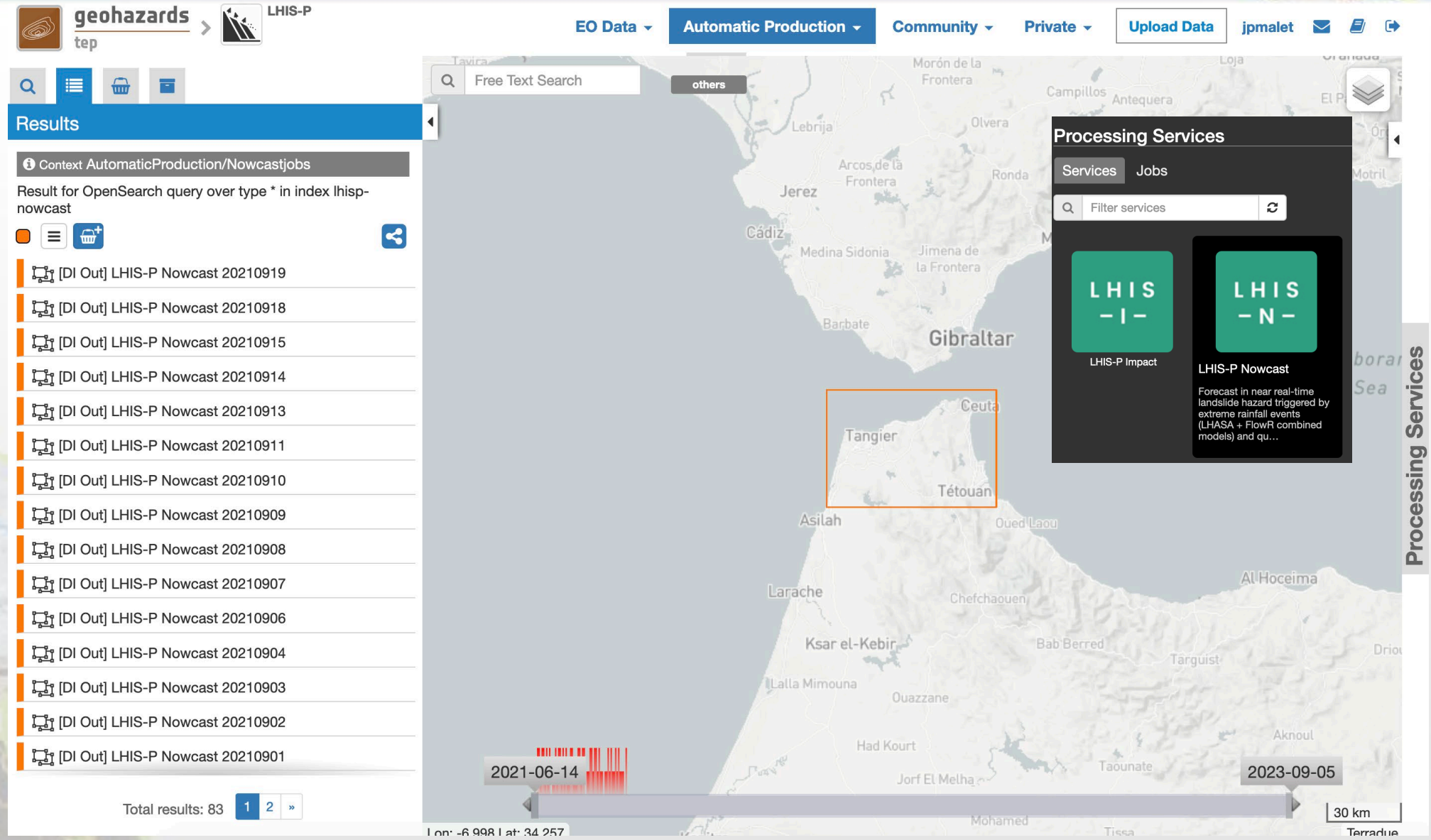
Goal: implement a platform prototype to respond to likely landslide events (in Near-Real Time, NRT) in order to provide estimates of parameters suitable to inform parametric insurance calculations.

→ Prototype for North Morocco (with state stakeholders)
→ All the developments are generic to be easily transferred to other countries and risk situations.



Application 2: Landslide Risk Financing

LHIS prototype implemented on GEP



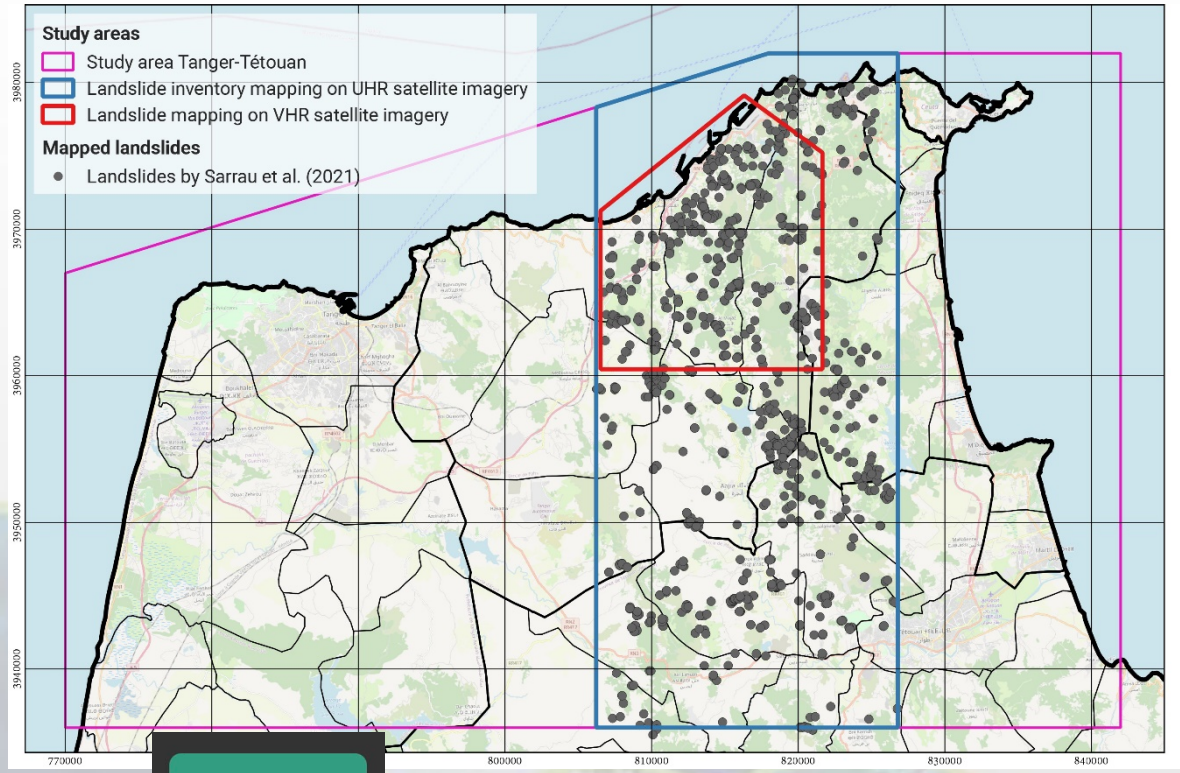
Terranum

Université de Strasbourg

NASA

Application 2: Landslide Risk Financing

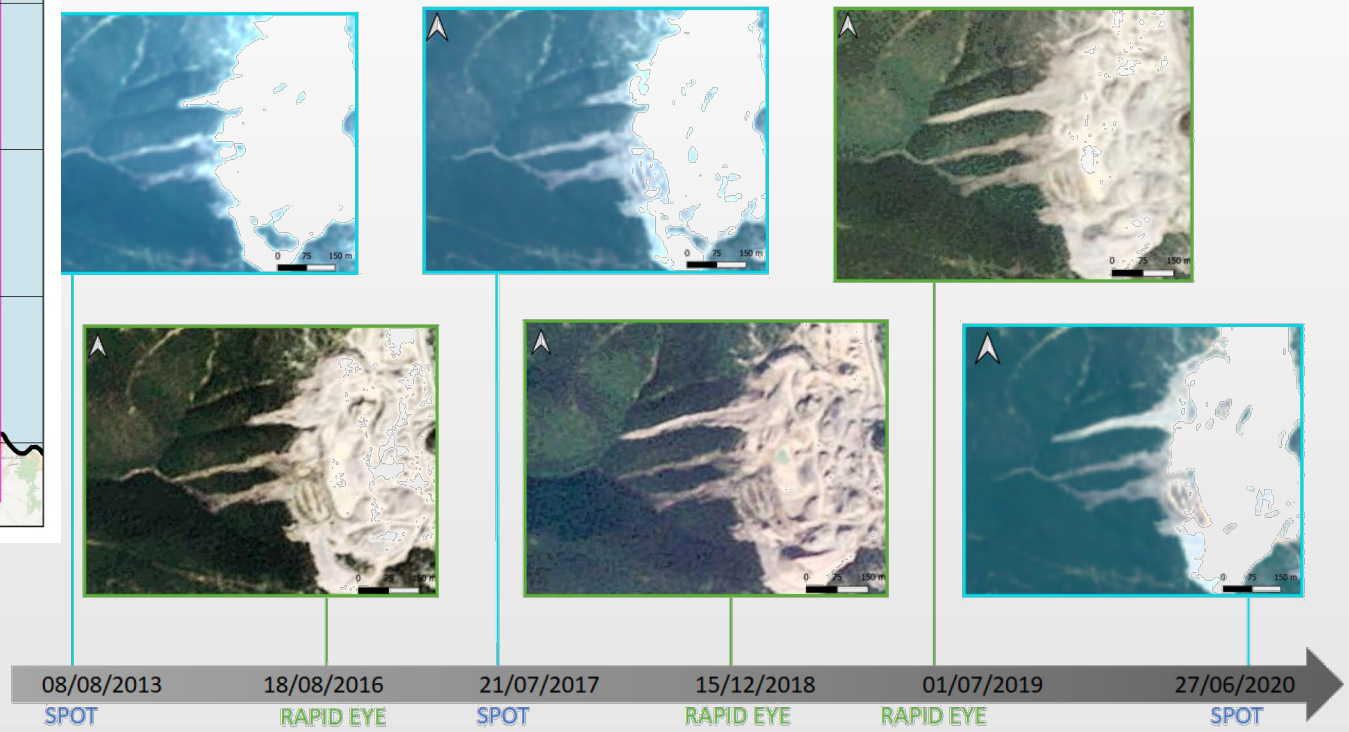
Morocco/Rif Area: multi-date landslide inventory



LHIS-P Impact

Module LHIS-Impact

Use of a combination of visual/expert interpretation and ALADIM service (period 2013-2020)



Application 2: Landslide Risk Financing

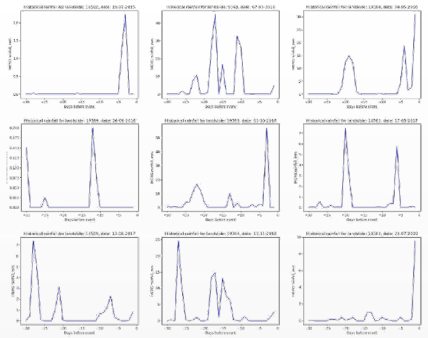
Module LHIS-Nowcast

LHIS -N-

LHIS-P Nowcast

Forecast in near real-time landslide hazard triggered by extreme rainfall events (LHASA + FlowR combined models) and qu…

IMERG nowcast



LHASA

Step 1

7-day Antecedent Rainfall Index (ARI)

Low

High

Susceptibility

Step 2

Low-Very Low

Moderate-High

Very High

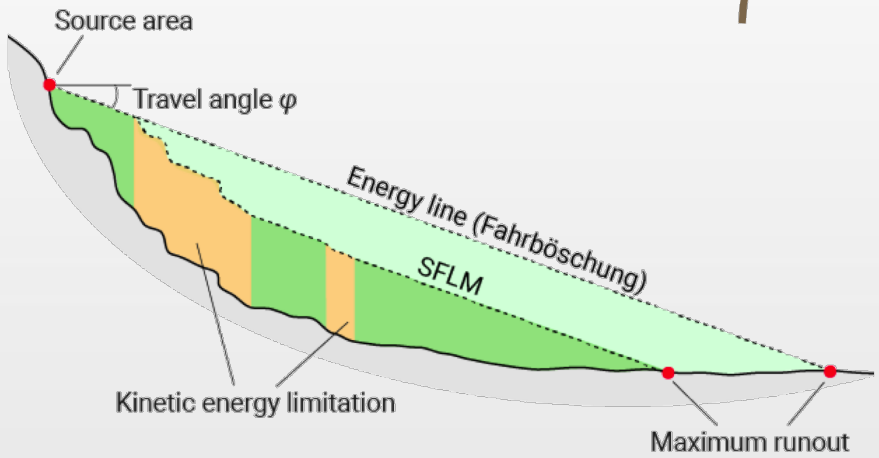
No Nowcast

Moderate-Hazard Nowcast

High-Hazard Nowcast

+

FLOW-R



Dynamic Landslide Hazard – source and propagation areas

Application 2: Landslide Risk Financing

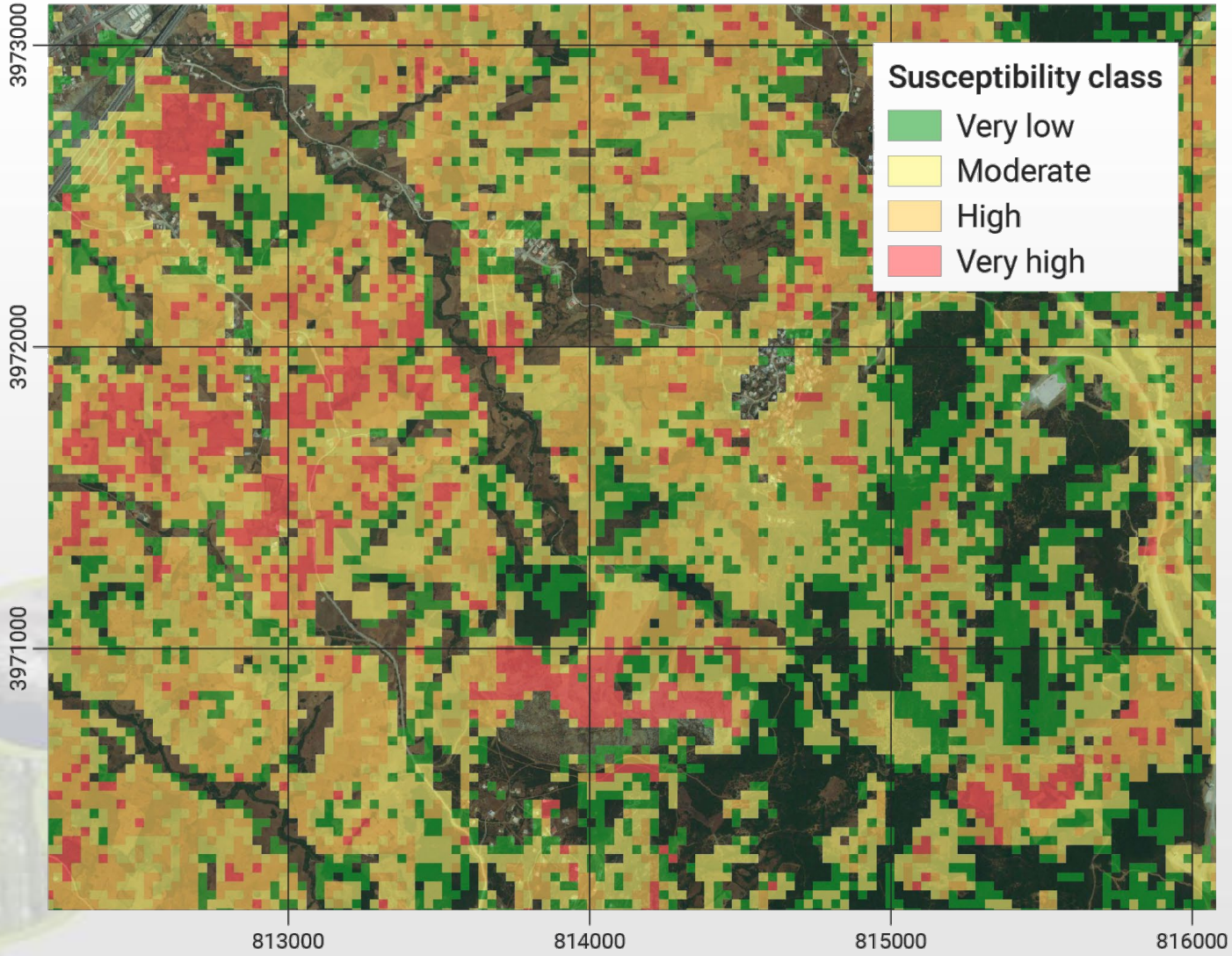
Module LHIS-Nowcast

LHIS -N-

LHIS-P Nowcast

Forecast in near real-time landslide hazard triggered by extreme rainfall events (LHASA + FlowR combined models) and qu…

Modelling landslide **source areas**

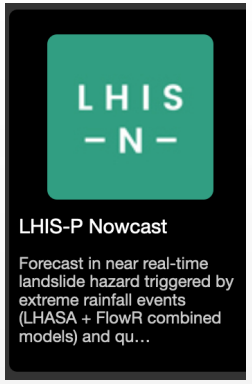


Terranum

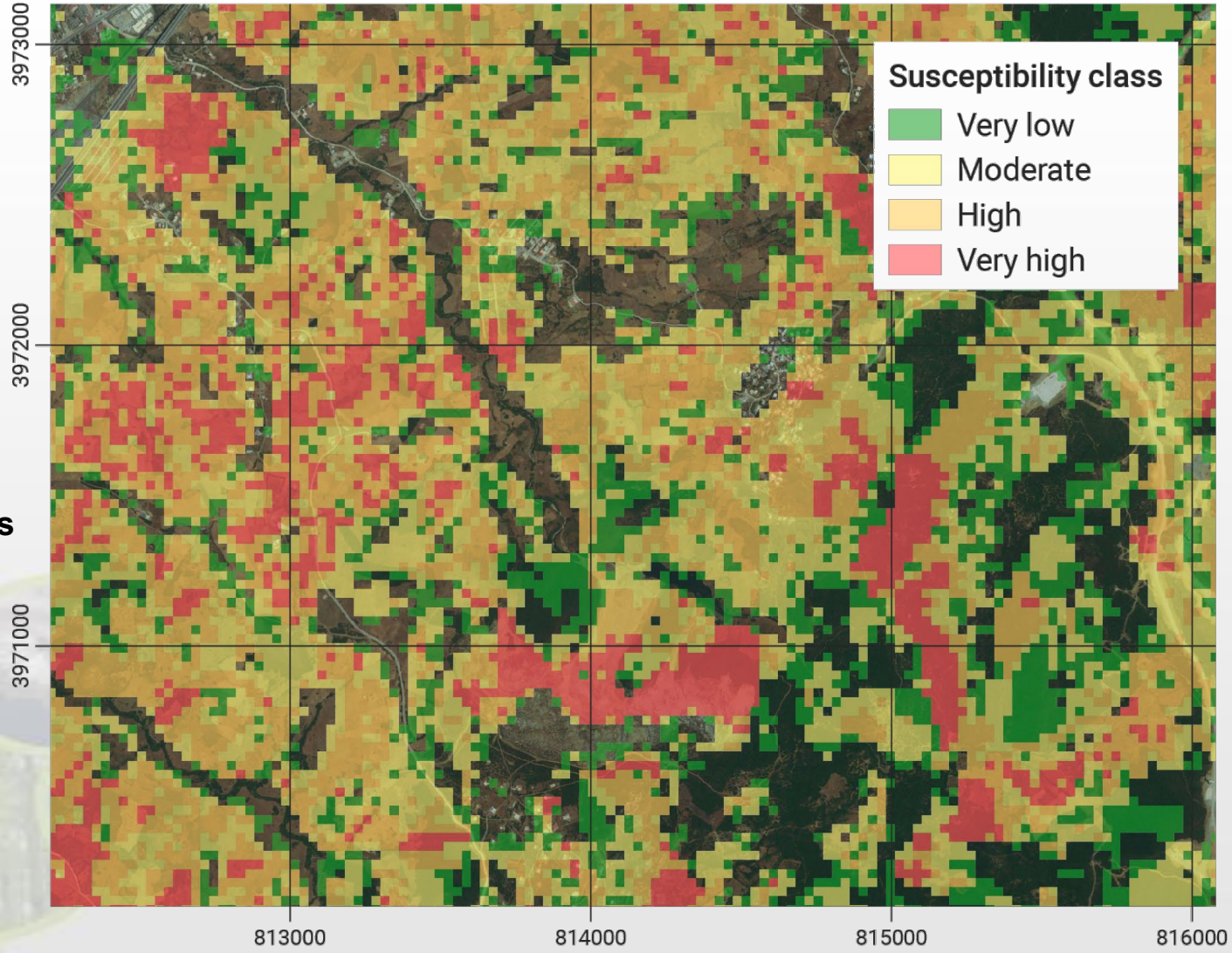
Université de Strasbourg

Application 2: Landslide Risk Financing

Module LHIS-Nowcast



Modelling landslide **propagation areas**



Application 2: Landslide Risk Financing

Module LHIS-Nowcast

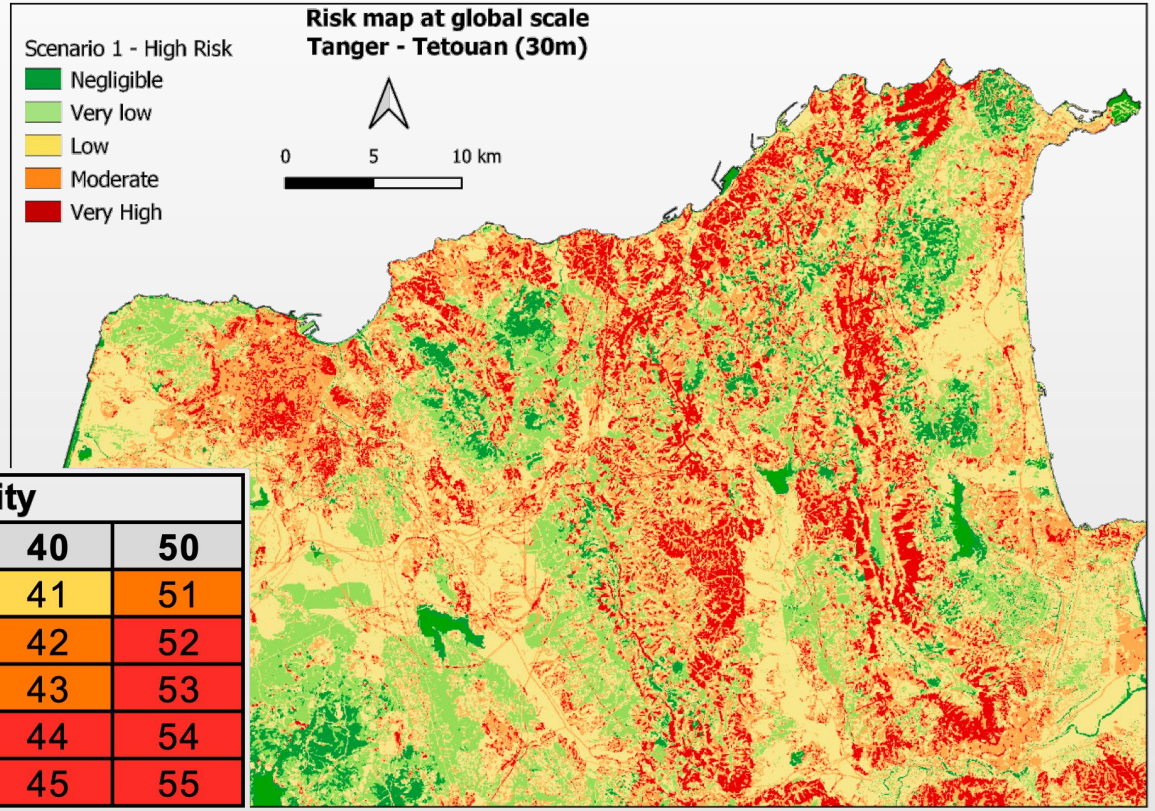
LHIS -N-

LHIS-P Nowcast

Forecast in near real-time landslide hazard triggered by extreme rainfall events (LHASA + FlowR combined models) and qu…

Potential Damage Index

- Croisement de la carte de susceptibilité avec les dommages potentiels
- Selon la matrice de risque
  → ajustable aux besoins



Modelling landslide **damage**

	Susceptibility				
PDI	**10**	**20**	**30**	**40**	**50**
1	11	21	31	41	51
2	12	22	32	42	52
3	13	23	33	43	53
4	14	24	34	44	54
5	15	25	35	45	55

Application 2: Landslide Risk Financing

On-going works

Morocco: from a region prototype to a national scale system

- Training with operational Moroccan stakeholders (February 2022, April 2022)
- On-going discussion with FSEC and Moroccan Ministry of Interior for service generalization and take up

Global:

- Implement a prototype system for tropical countries subjected to extreme rainfall events ; Demo over Haïti
- On-going discussion with NAMRIA – National Mapping and Ressource Information Authority (Philippines)

Application 3: Global Landslide Data

Application 3: Advancing EO-based landslide inventories for extreme forcing events (heavy rains, high-magnitude earthquakes)

The goal of this application is to share methodologies for the establishment of landslide inventories across different geologic and morphologic zones. In this activity we will propose standard for creating and publishing EO-based landslides inventories, with the goal of developing an online open system to share algorithms and inventories using SAR and optical methodologies. This work will be done in coordination with the newly formed LandAware consortium's Data Working Group, with EGS (EuroGeoSurveys) and with JRC

Methodologies

Inventories

- New, open methods for SAR and optically-derived inventories. Definition of quality criteria for validating EO-based inventory and store the information, data standards
- System to store and disseminate inventories on-line

Models

- Comparison and sharing of models that provide automatic mapping capabilities and calculation of advanced statistics from the EO database.
- Establish correlation with triggers (thresholds, scaling laws) for benchmark inventories.

Demonstrator Leads: Dalia Kirschbaum, Jean-Philippe Malet (CNRS/EOST) and Olivier Dewitte (RMCA).

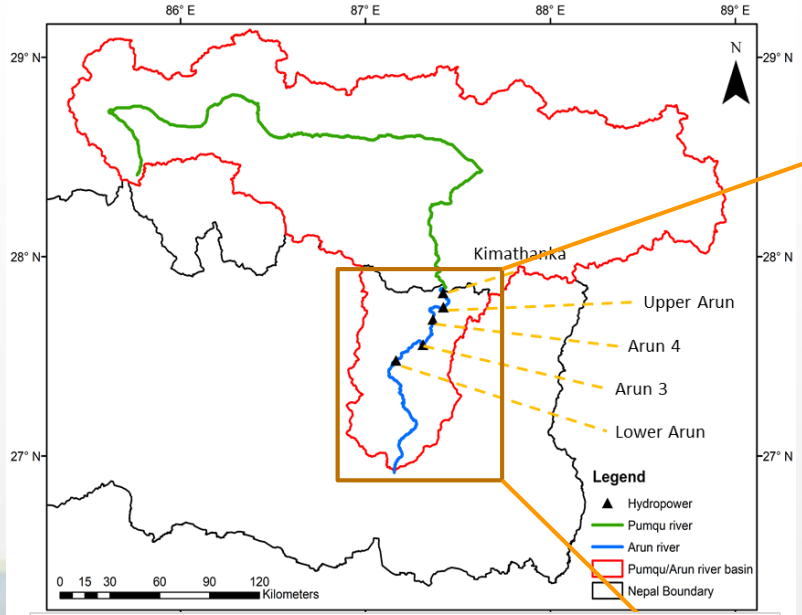
Industry Participants: LandAware Consortium, World Landslide Forum, USGS, EuroGeoSurveys, JRC and other geological mapping agencies

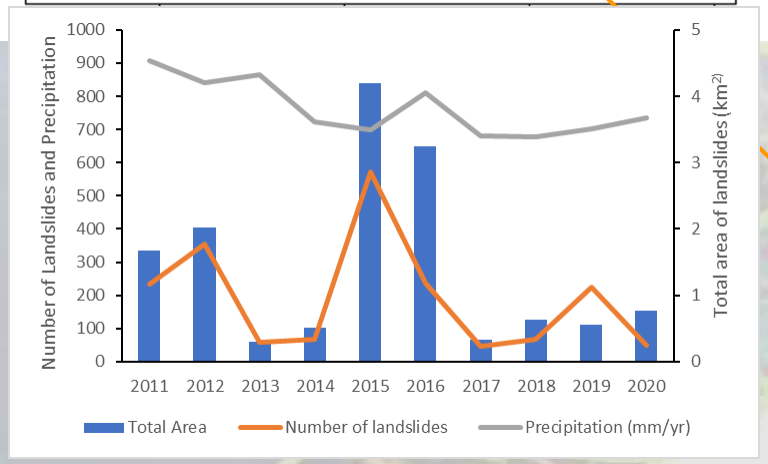
Application 3: Global Landslide Data

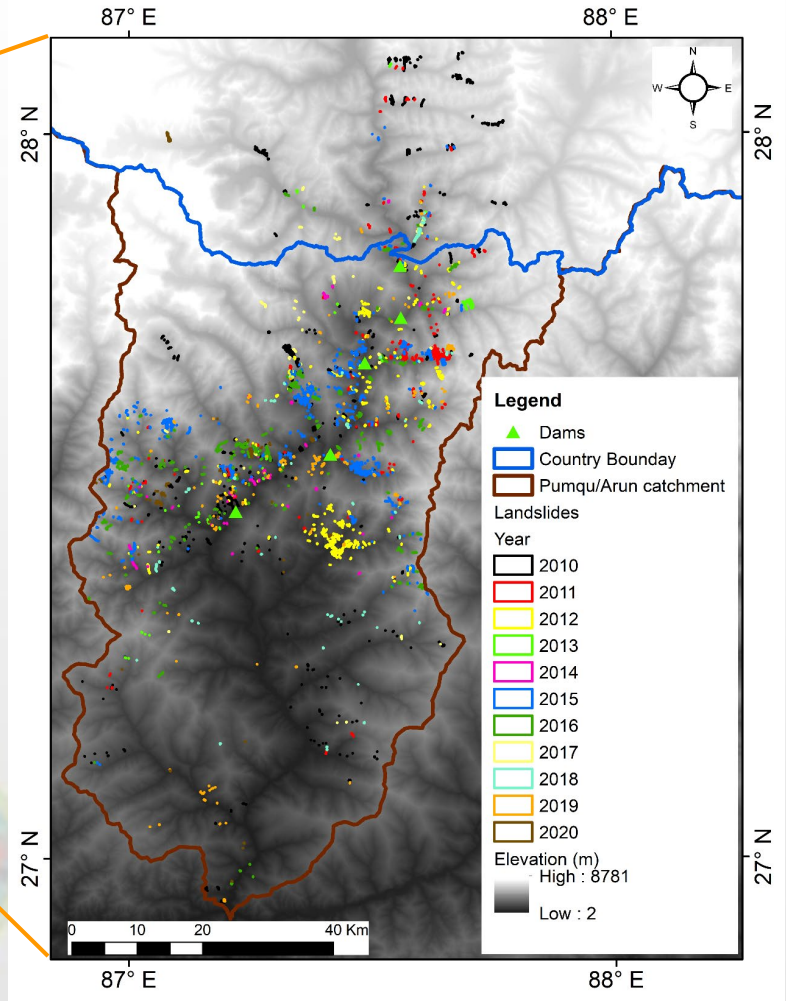
- Kirschbaum (NASA) and Mirus (USGS) co-leading a Landslide Early Warning System (LEWS) Data Working Group
- LandAware Kickoff Meeting, December 2020
- LEWS Data WG KO (Jan. 2021) + WG meetings (March 2021, Sept. 2021)

- **Topics:**
  - LEWS Data Review – White Paper and Journal Article
  - Collection of Benchmark Datasets
  - Repository and Metadata for inventories and other products
  - What is an ideal landslide benchmark dataset?

Multitemporal landslide inventory for Arun river basin, Nepal using Planet imagery and Semi-Automatic Landslide Detection (SALaD)





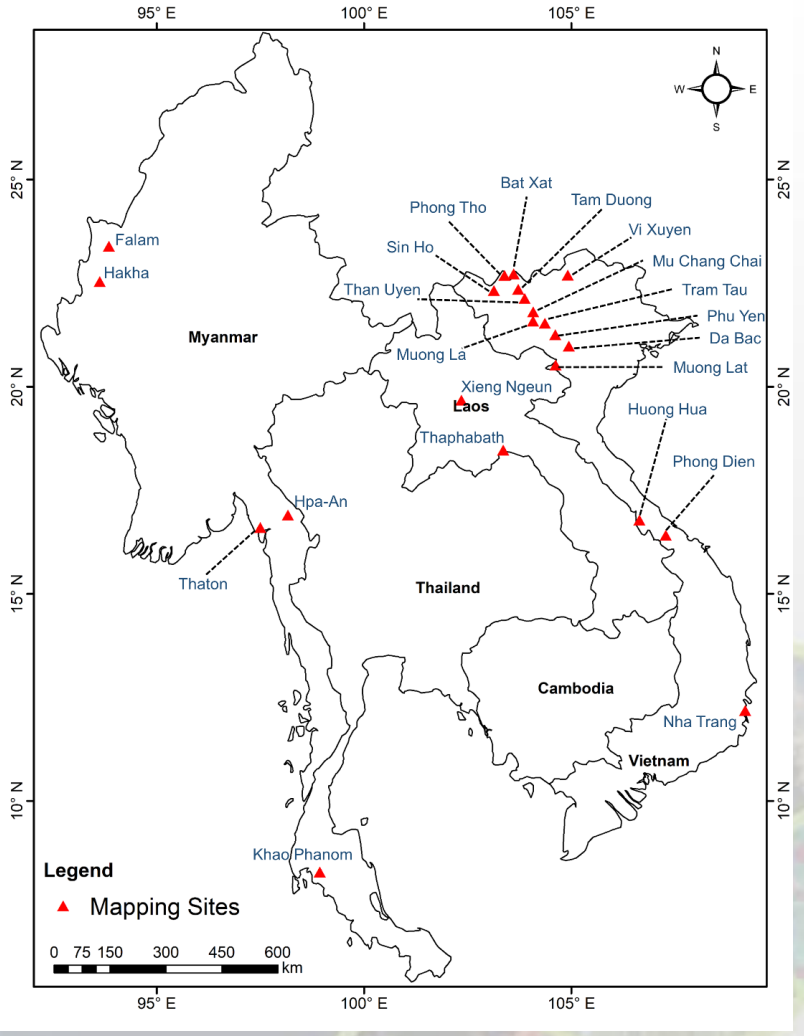


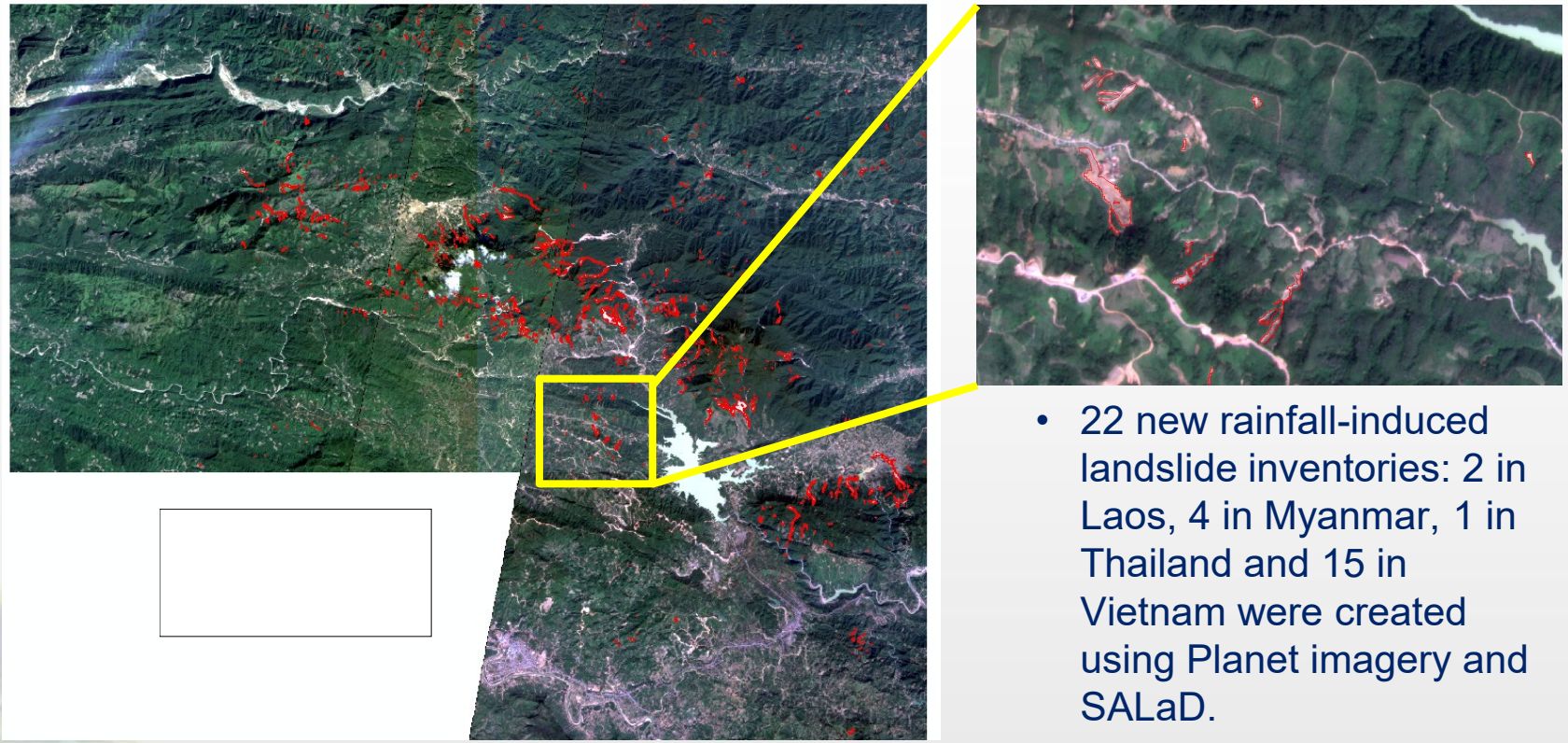
- Generated in response to "Support to World Bank's Risk Assessment of Landslides in Upper Arun Hydropower Project",
- Years = 2010 - 2020
- Number = 2439
- Minimum size = 97 m^2
- Maximum size = 357089 m^2
- Imagery: PlanetScope and RapidEye
- Method: SALaD (Amatya et al, 2021a)

Data available at: https://nsidc.org/data/HMA2_MTLI/versions/1

Credits: Pukar Amatya (UMBC/NASA) and Dalia Kirschbaum (NASA)

Rainfall-induced landslides inventories for Lower Mekong region using Planet imagery and SALaD





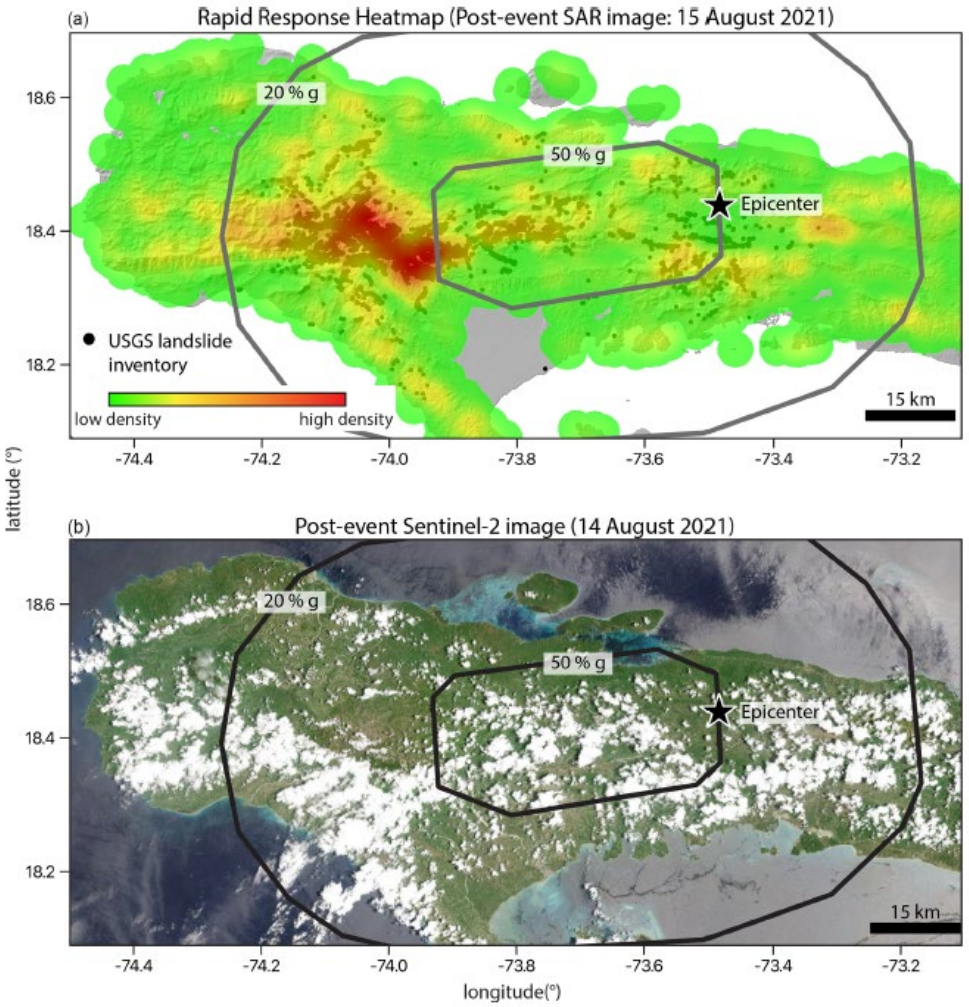
- 22 new rainfall-induced landslide inventories: 2 in Laos, 4 in Myanmar, 1 in Thailand and 15 in Vietnam were created using Planet imagery and SALaD.

Amatya et al. (2021b)

Data available at: https://doi.org/10.6084/m9.figshare.14199227
Publication: https://doi.org/10.1002/gdj3.145

Credits: Pukar Amatya (UMBC/NASA) and Dalia Kirschbaum (NASA)

Landslide heat map generated using SAR backscatter change (in GEE)

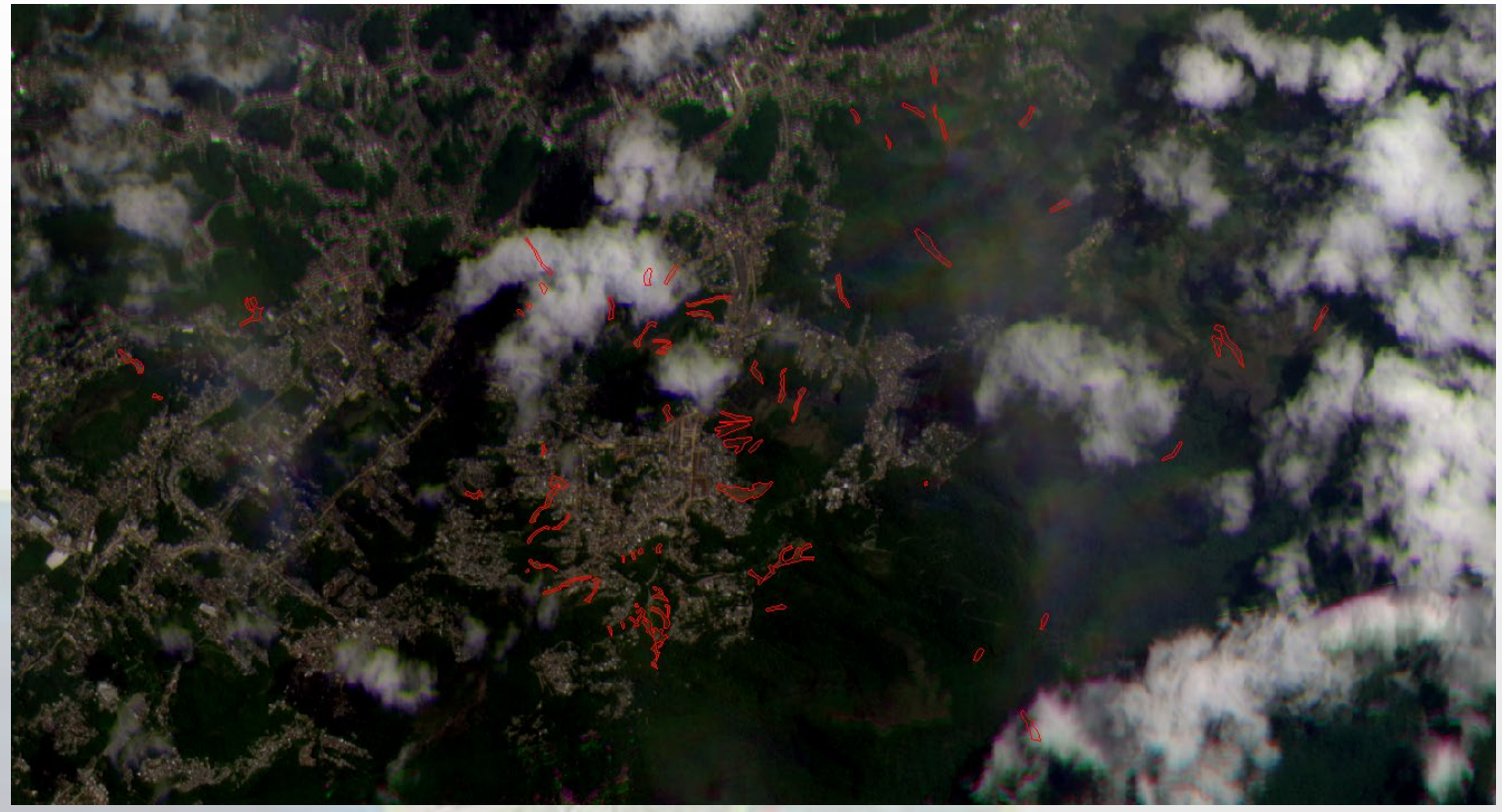


- Development of SAR backscatter change approach in the cloud-based Google Earth Engine (GEE) that uses multi-temporal stacks of freely available data from the Copernicus Sentinel-1 satellites to generate landslide density heatmaps for rapid detection (Handwerger et al, 2022).
- Real-time rapid response heatmap for the August 14, 2021 earthquake-triggered landslides in Haiti a day after the event.
- Heavy cloud cover after the event hindered landslide mapping from optical imagery

Publication: https://doi.org/10.5194/nhess-22-753-2022

Credits: Alexander Handwerger (UCLA/JPL), Pukar Amatya (UMBC/NASA), Mong-Han Huang (UMD) and Dalia Kirschbaum (NASA)

Landslide mapping for February 15, 2022, precipitation event in Petropolis, Brazil

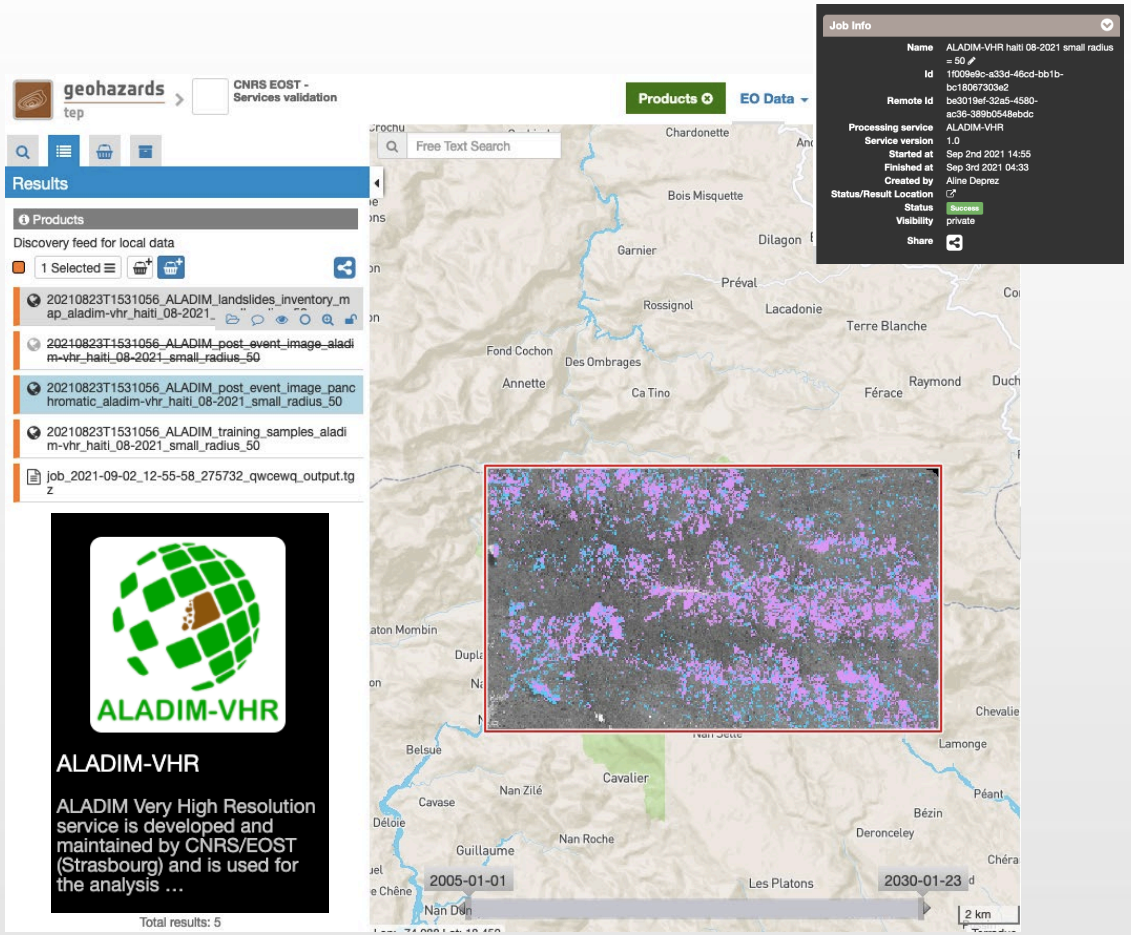


- Manual inventory generated from PlanetScope imagery on request from Petrópolis Civil Defense.
- 68 landslides were mapped

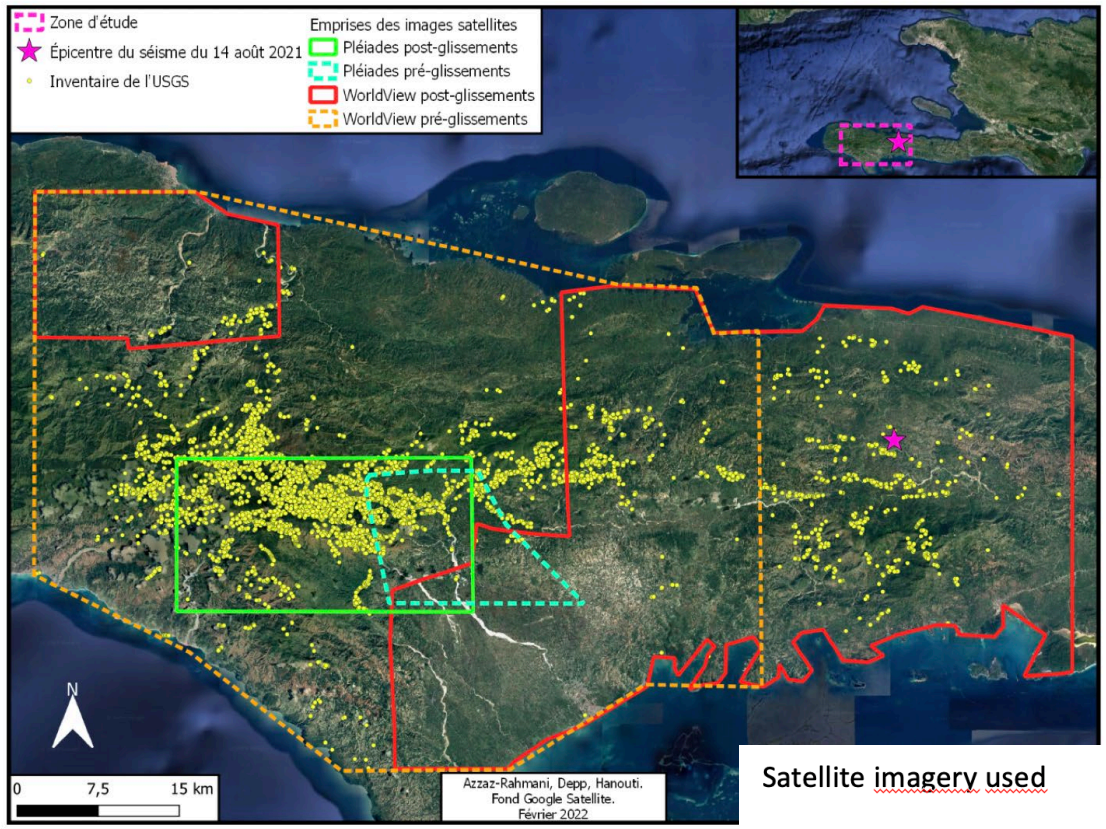
Credits: Rachel Soobitsky (SSAI/NASA), Pukar Amatya (UMBC/NASA) and Dalia Kirschbaum (NASA)

Landslide inventory mapping / Haïti

ALADIM VHR-Pléiades
mapped landslides post Haiti Earthquake using GEP



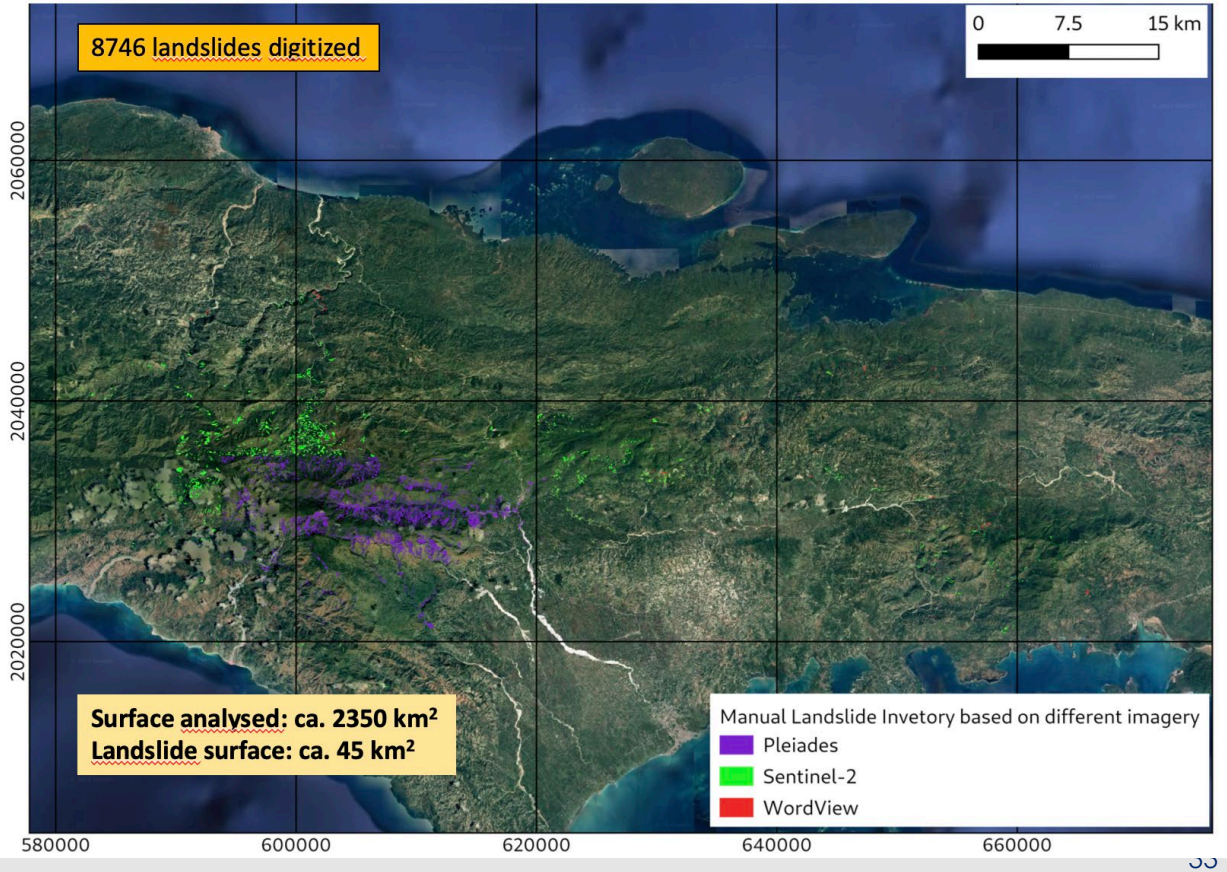
Landslide inventory mapping / Haïti



Satellite imagery used

sentinel-2	10 m
Pléiades	0.5 m / 2 m
WorldView 3	0.46 m

Landslide reference inventory: polygons



Landslide inventory mapping / Haïti

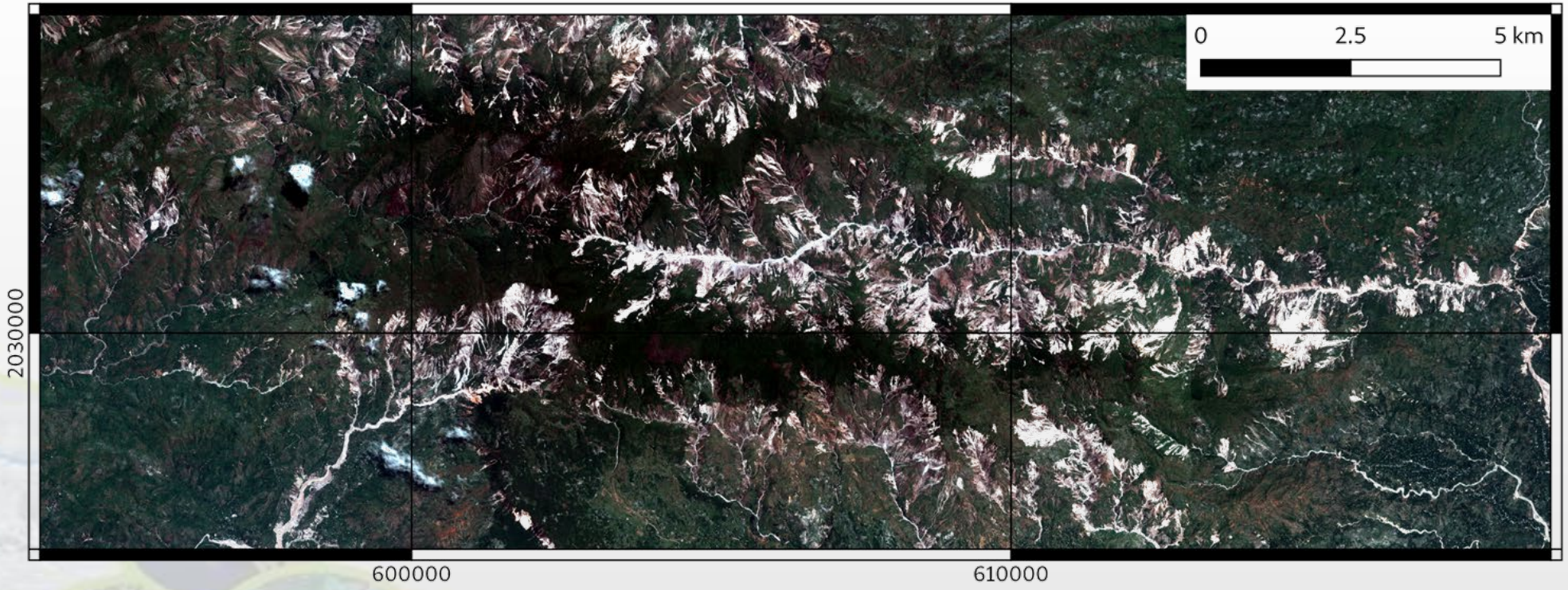
ALADIM VHR-Pléiades
mapped landslides post Haiti Earthquake using GEP

Source: Pléiades

Mono-date detection
using machine learning

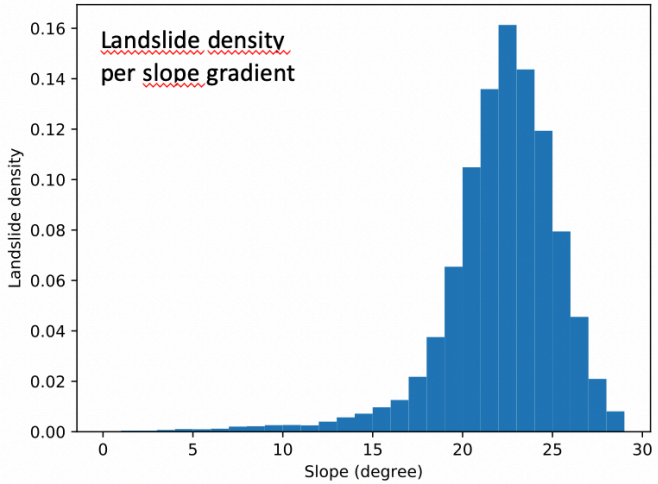
Post-event : 23/08/2021
Input: MS image

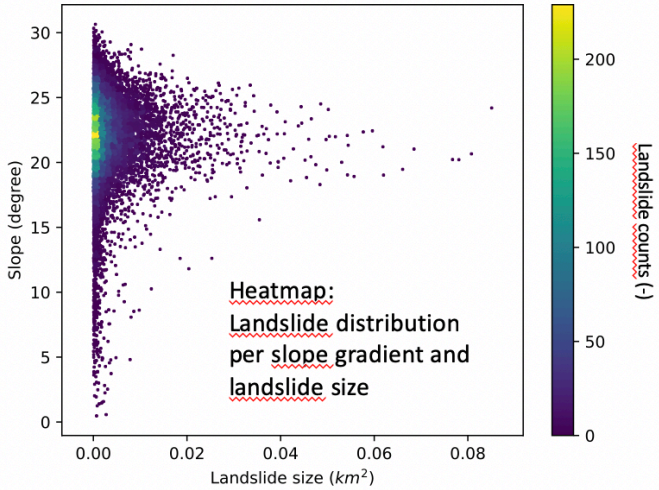
Credit: A. Déprez
(EOST/A2S)



Landslide inventory mapping / Haïti

Landslide reference inventory: some statistics

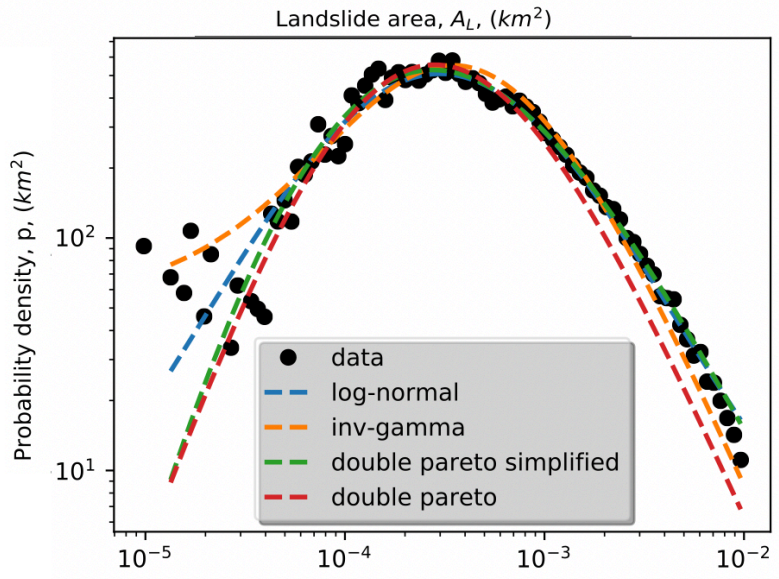




8746 landslides digitized

distribution	alpha	beta	t	m	c	R
DP simplified	7.25e-01	4.48e+00	1.04e-04	1.51e-02	5.22e-06	9.66e-01
DP	9.74e-01	3.48e+00	2.23e-04			9.49e-01
distribution	alpha	eta	lambda	sigma	mu	R
log-normal	6.23e+00			2.75e+00	-8.12e+00	1.00e+00
inv-gamma	1.00e+00	1.20e-02	3.13e-02			9.34e-01

Landslide Probability Density Functions and models



Many progress since September 2021

- Data tasking and access on-going (except SAOCOM + CSK)
- Target user groups and services identified
- Many publications on-going