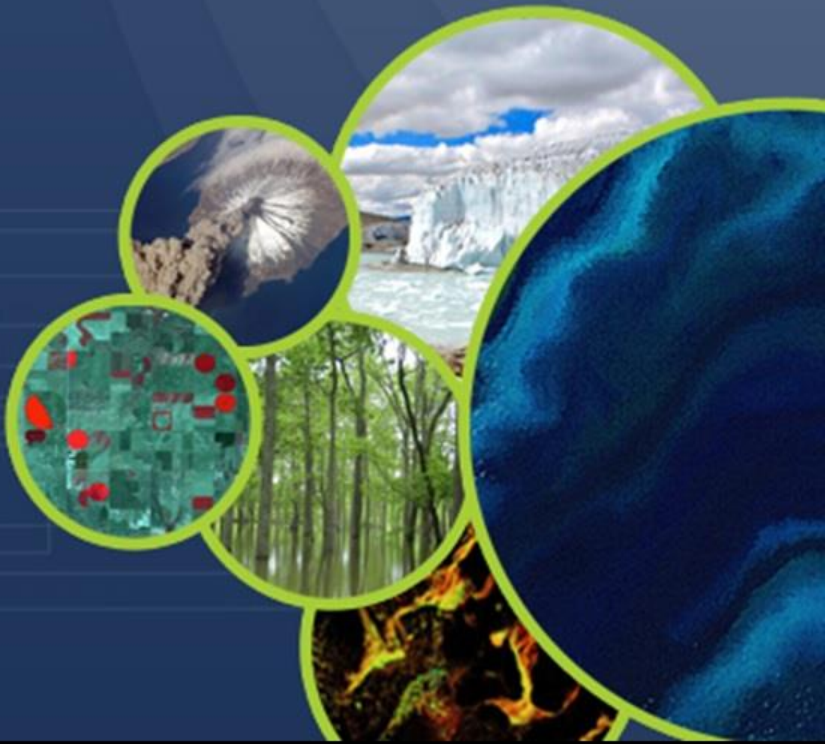
CEOS

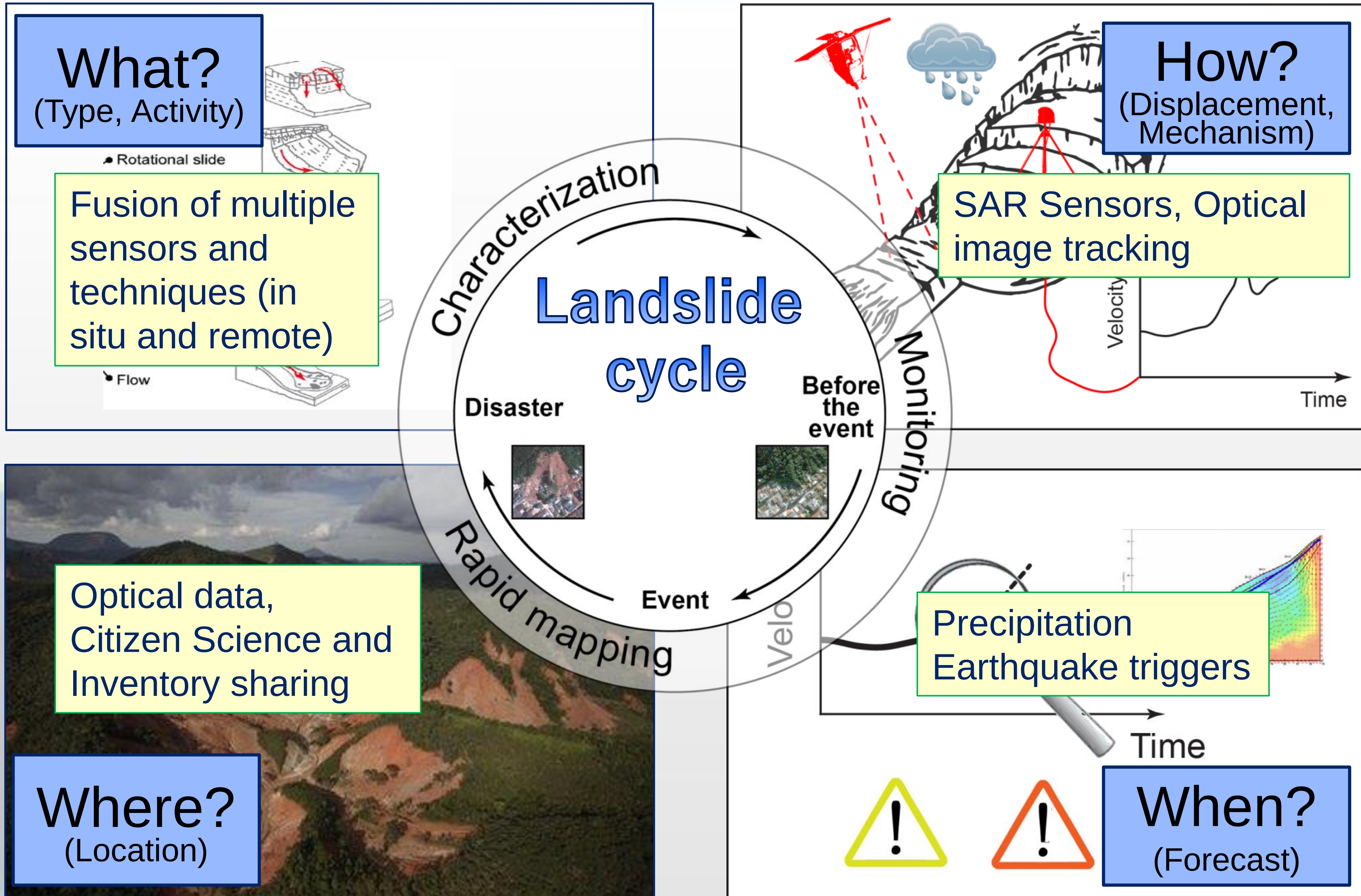
Committee on Earth Observation Satellites

Landslide Pilot Working Group Presentation

September 24-27, 2019
Iceland



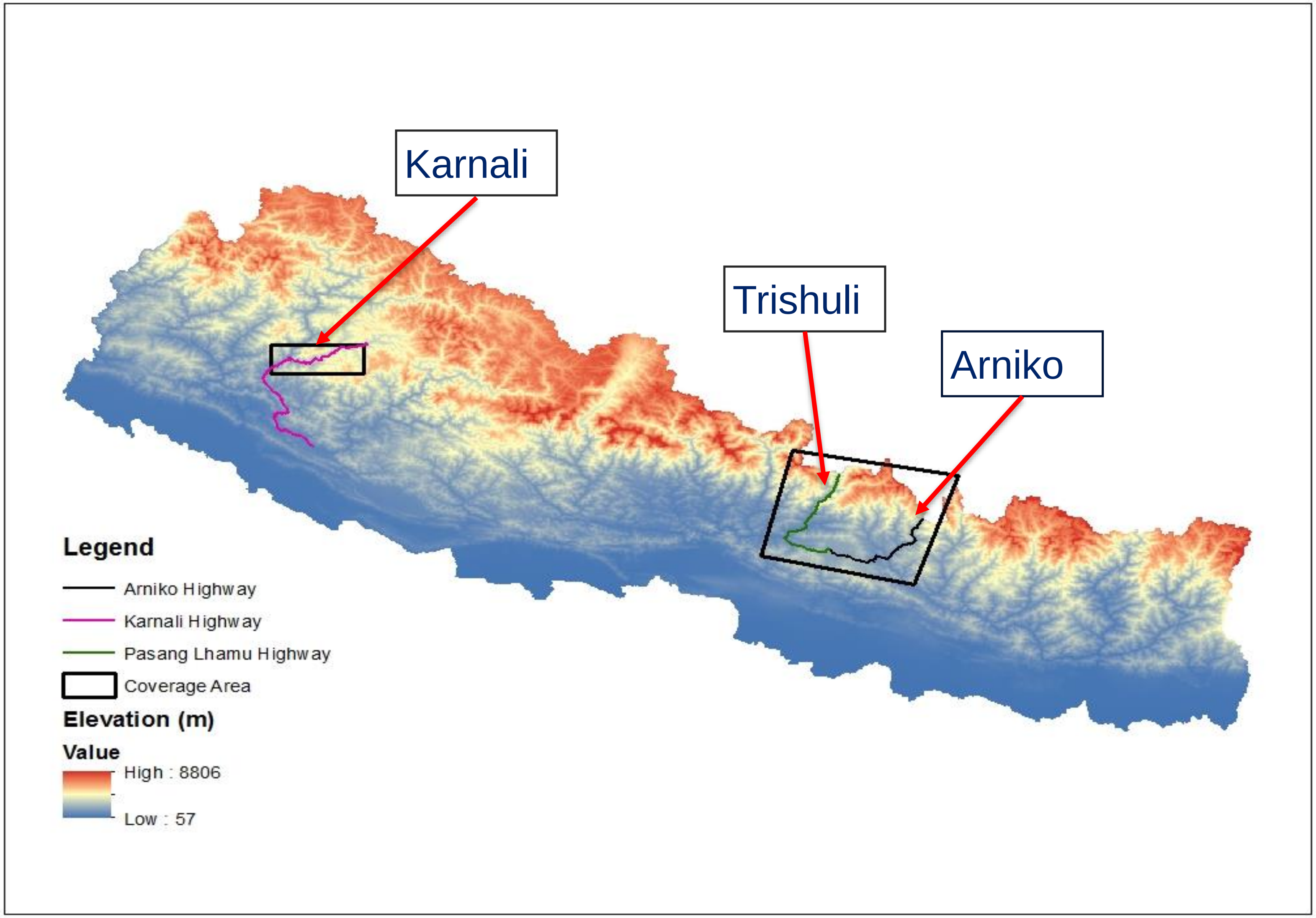
Integration of satellite platforms for understanding landslides



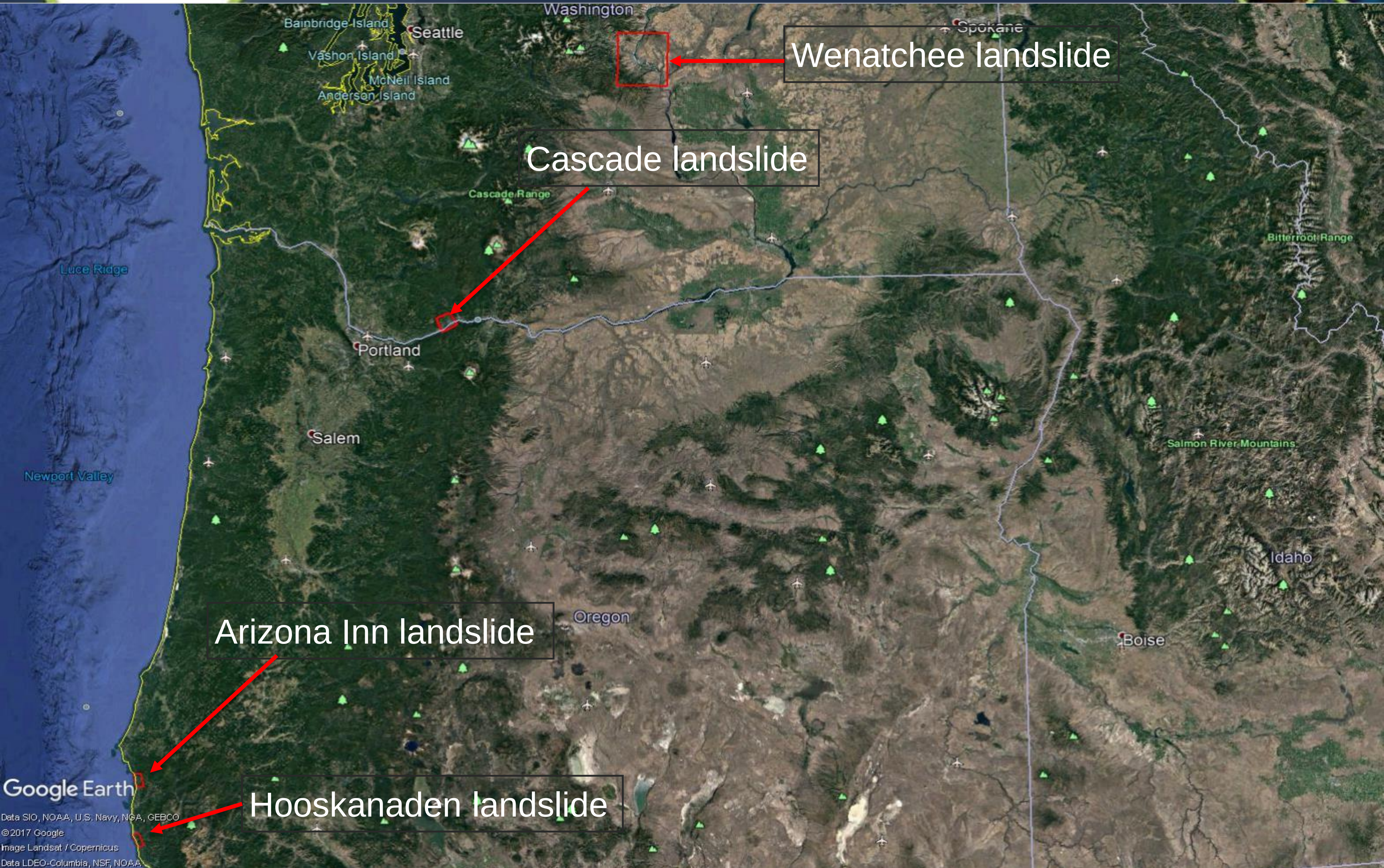
Regional study areas and leads

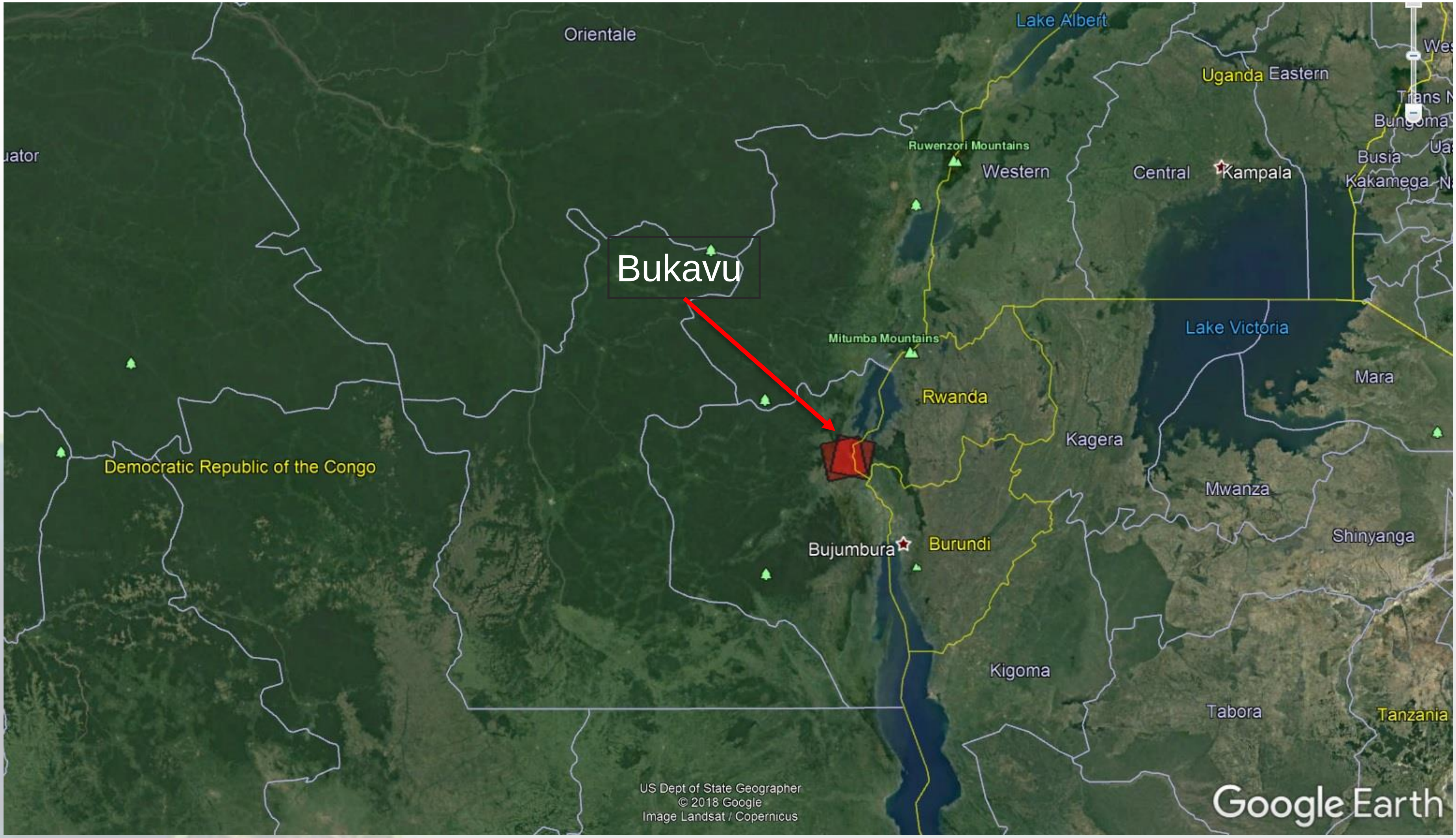
Region	*Regional Point of Contact*
Nepal	**Nick Rosser, Sigrid Roessner, Dalia Kirschbaum**
Pacific Northwest, US	**Jonathan Godt, Dalia Kirschbaum**
Eastern Africa	***Olivier Dewitte***
Caribbean (Cuba/Lesser Antilles)	***Georgina Bennett, Jean-Philippe Malet***
China	***Zeng-Guang Zhou***

Nepal data request areas

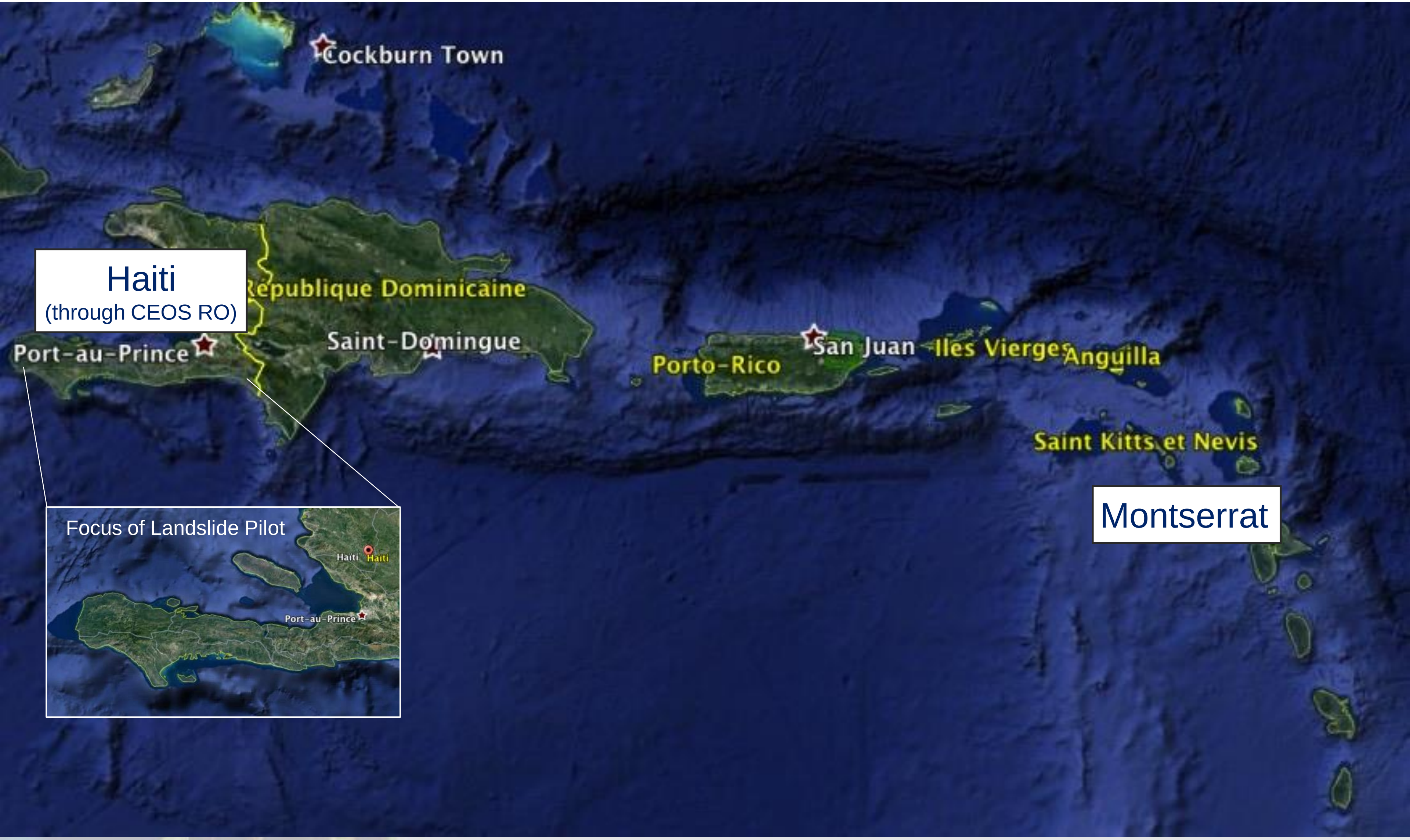


PNW data request areas




Bukavu
Orientale
Lake Albert
Uganda
Eastern
Ruwenzori Mountains
Western
Central
Kampala
Busia
Kakamega
Lake Victoria
Mitumba Mountains
Rwanda
Kagera
Mara
Democratic Republic of the Congo
Mwanza
Shinyanga
Bujumbura
Burundi
Kigoma
Tabora
Tanzania
US Dept of State Geographer
© 2018 Google
Image Landsat / Copernicus
Google Earth

Caribbean data request area



DLR/TerraSAR-X

Total quota: Decided by DLR upon review of the proposal

Ordered:

1. Nepal: Acquisition in Arniko study area of Nepal. Trishuli not feasible.
2. PNW: Not possible
3. East Africa: Not possible

Status: Acquisition ongoing for Arniko and data hosted in DLR ftp.

CSA/Radarsat-2

Quota available:

1. Nepal: 30 tasking, 30 archived
2. PNW: 30 archived

Status: Requested quad pol data but were asked to redo contract, but have not yet heard back

ASI/COSMO-SkyMed

Total quota: 300 images/year

Ordered:

Nepal: Trishuli (72 asc/72 des), 2015 earthquake data also available but with permission from ASI

PNW: Wenatchee (30 asc/ 30 des), Cascade (30 asc/30 des).

East Africa: Bukavu (42 asc/42 des) (end in January 2019 - possible extension through volcano pilot but difficulities among the volcano group and the landslide group in RDC)

Status: Acquired data hosted in ASI ftp (need for a central repository

CNES - Pleiades/SPOT

Pleiades

Total quota: 40000 km^2 for the life of the project.

Ordered:

1. Nepal: Karnali (22242 km^2), Arniko (300 km^2)
2. PNW: Eel river (6605 km^2), Southern Oregon Coast (1535 km^2)
3. Caribbean: Montserrat (56 km^2, 2018) + new request 2019

Status: data delivered directly to requestor.

Quota of 6000 km2 available in Landslide Pilot (status on March 2019)

What is still available for the Pilot?

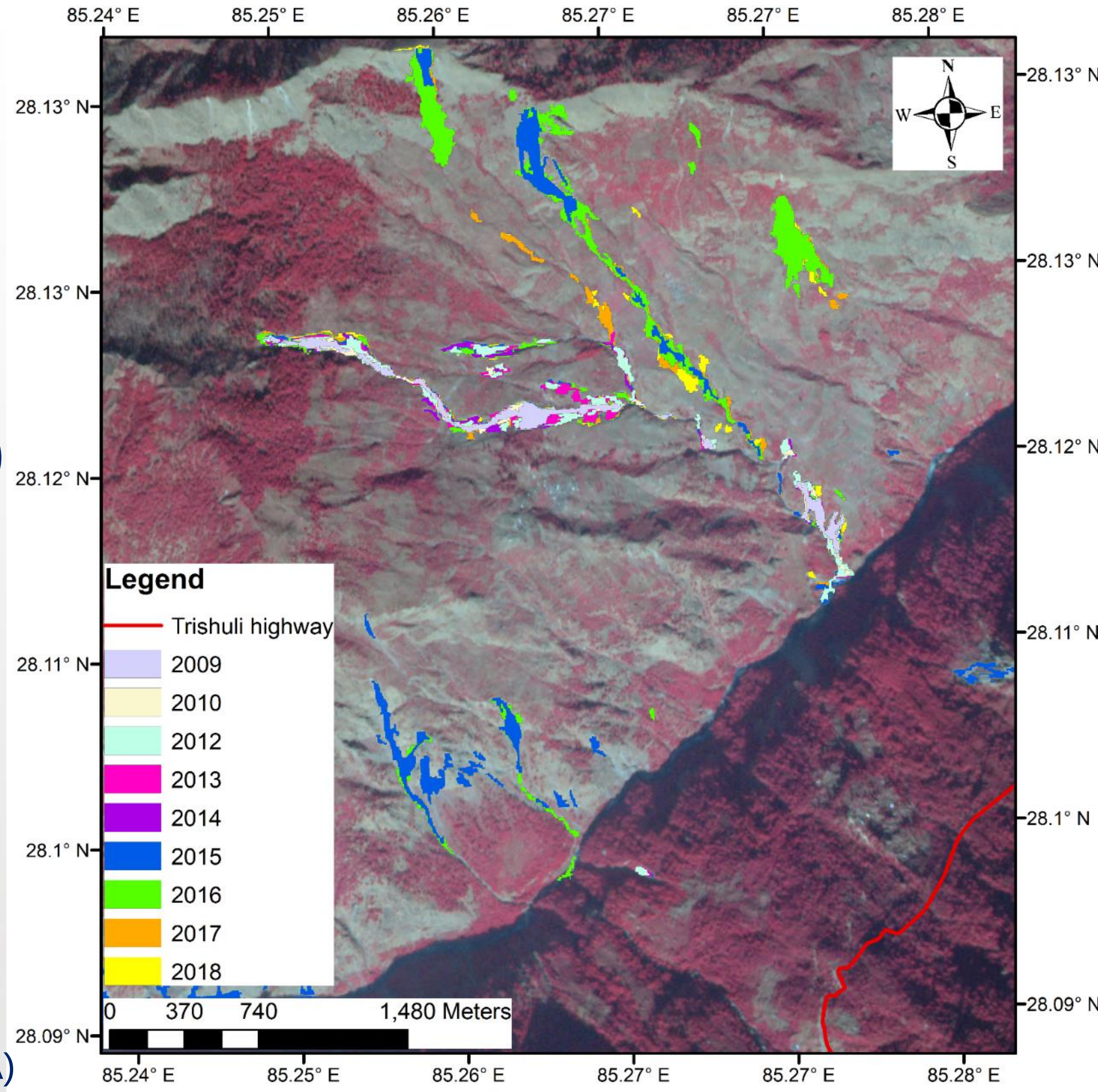
Nepal Study Sites: Preliminary Results

Multi-temporal landslide inventory creation using Machine Learning

Method: Python based, open source

Source: RapidEye at 5 m resolution (NASA Databuy)

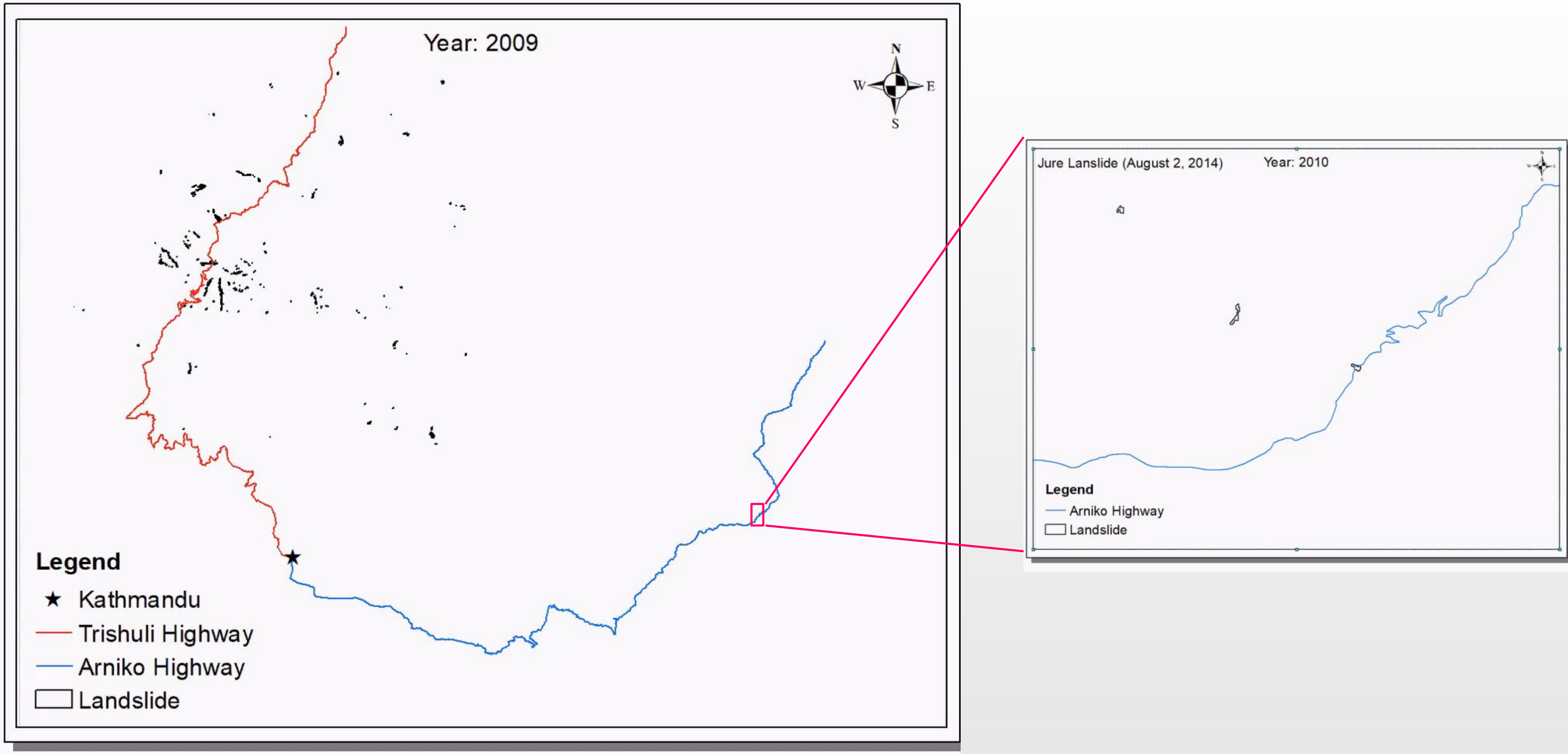
Year = 2009-2018



Pukar Amatya (USRA)/Dalia Kirschbaum (NASA)
Amatya et al. *in prep*

Landslides along Arniko and Trishuli highway (2009 – 2018)

Multi-temporal landslide inventories along Nepal highways using RapidEye data

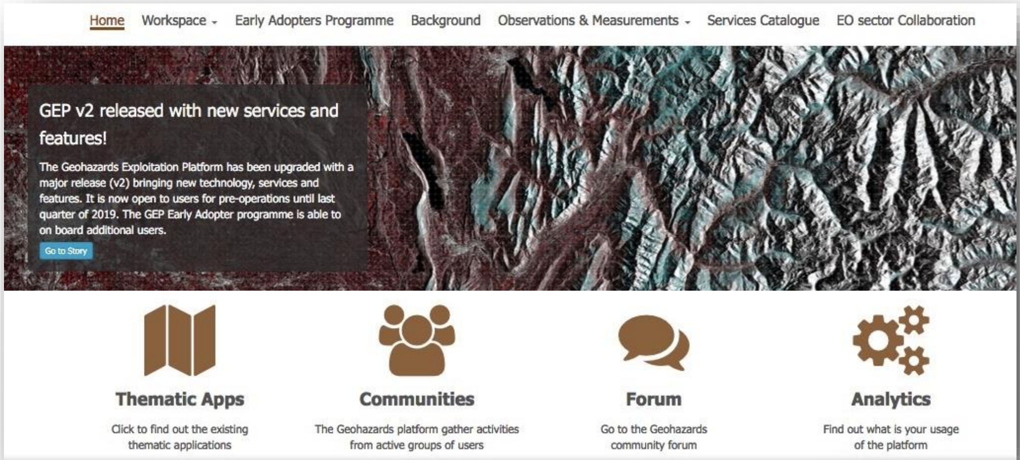


Pukar Amatya (USRA)/Dalia Kirschbaum (NASA)

Amatya et al., *in prep*

ALADIM SERVICE: AUTOMATIC LANDSLIDE DETECTION AND INVENTORY MAPPING

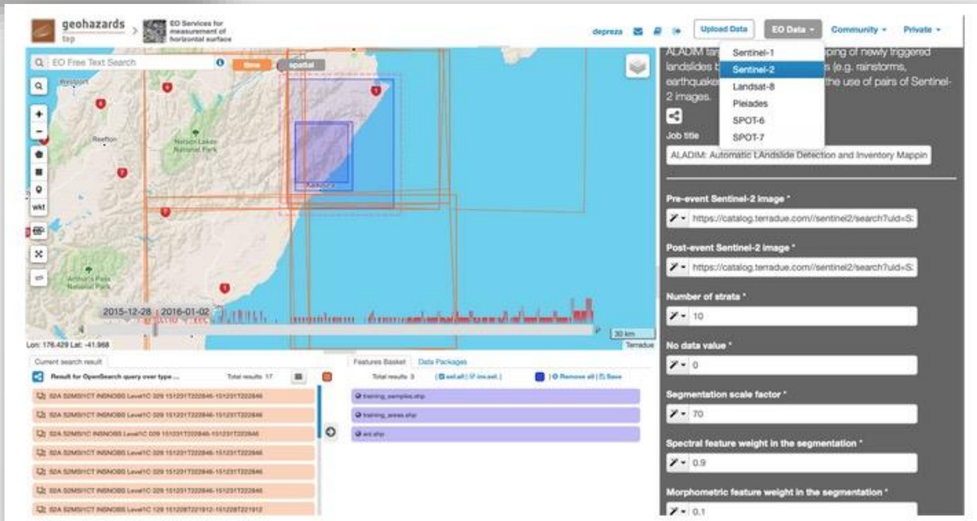
Available on geohazards tep → **ALADIM-S2 and ALADIM-VHR**



ALADIM

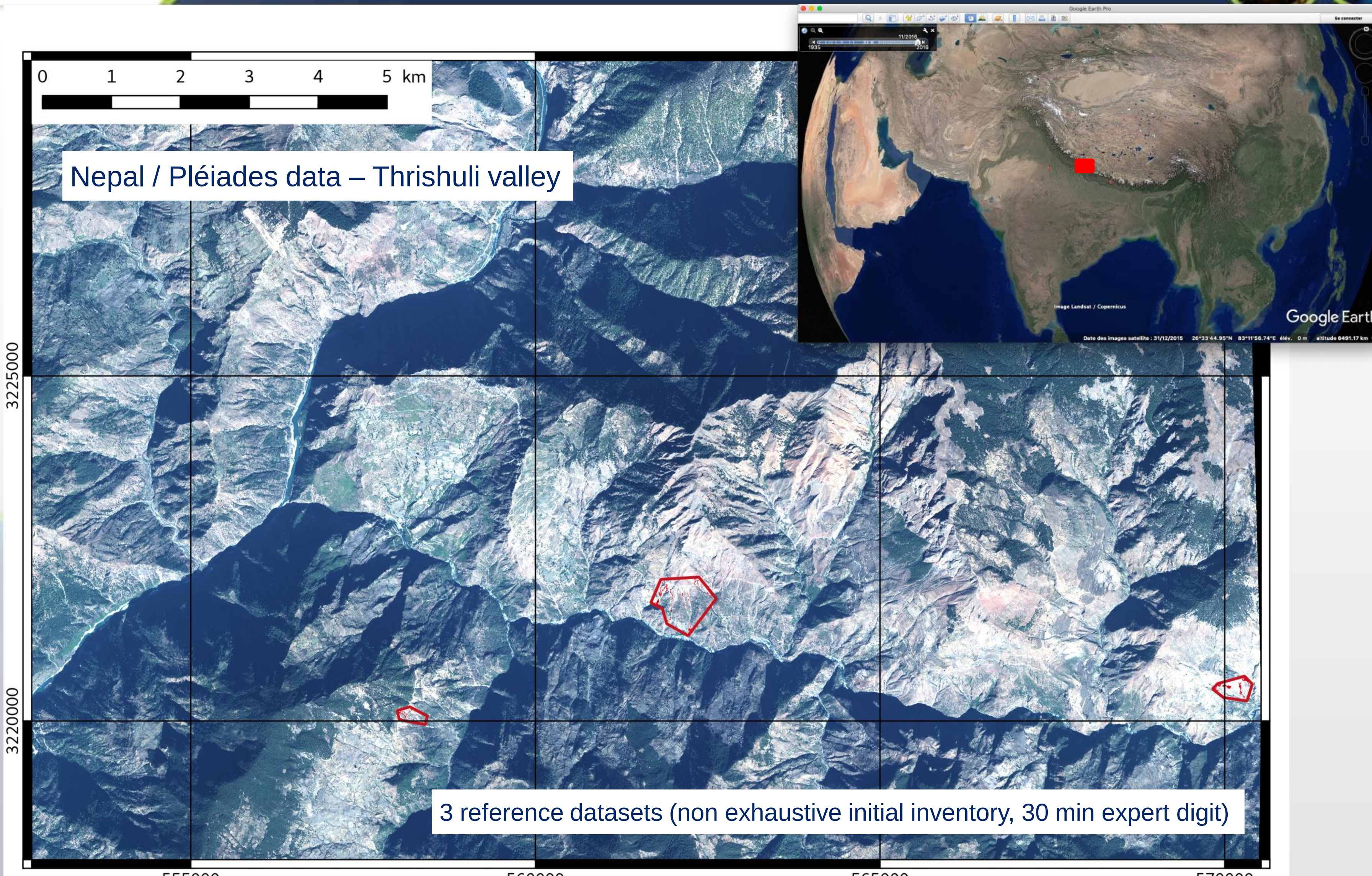
Service selection

Service use



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

ALADIM SERVICE: AUTOMATIC LANDSLIDE DETECTION AND INVENTORY MAPPING



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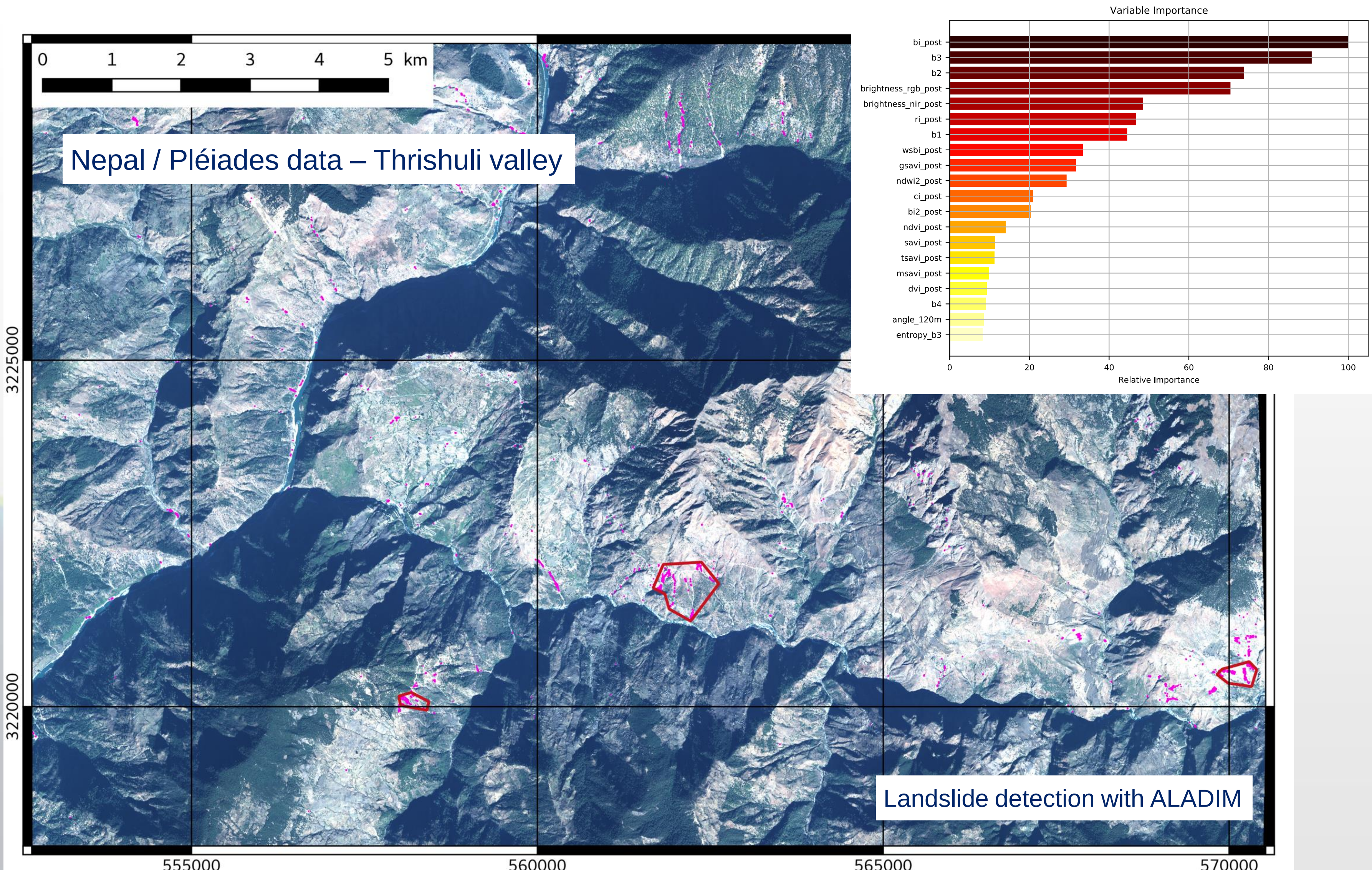

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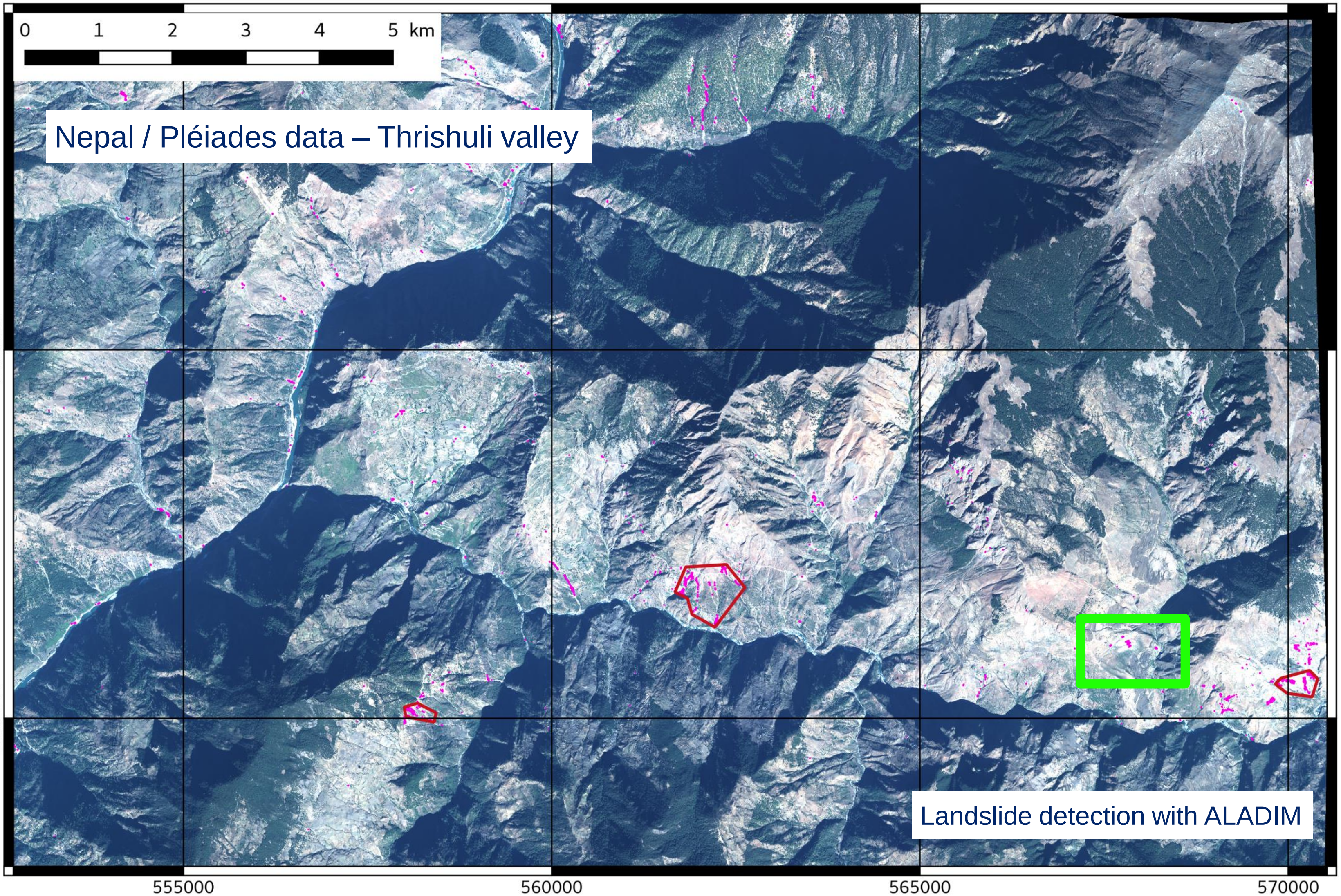

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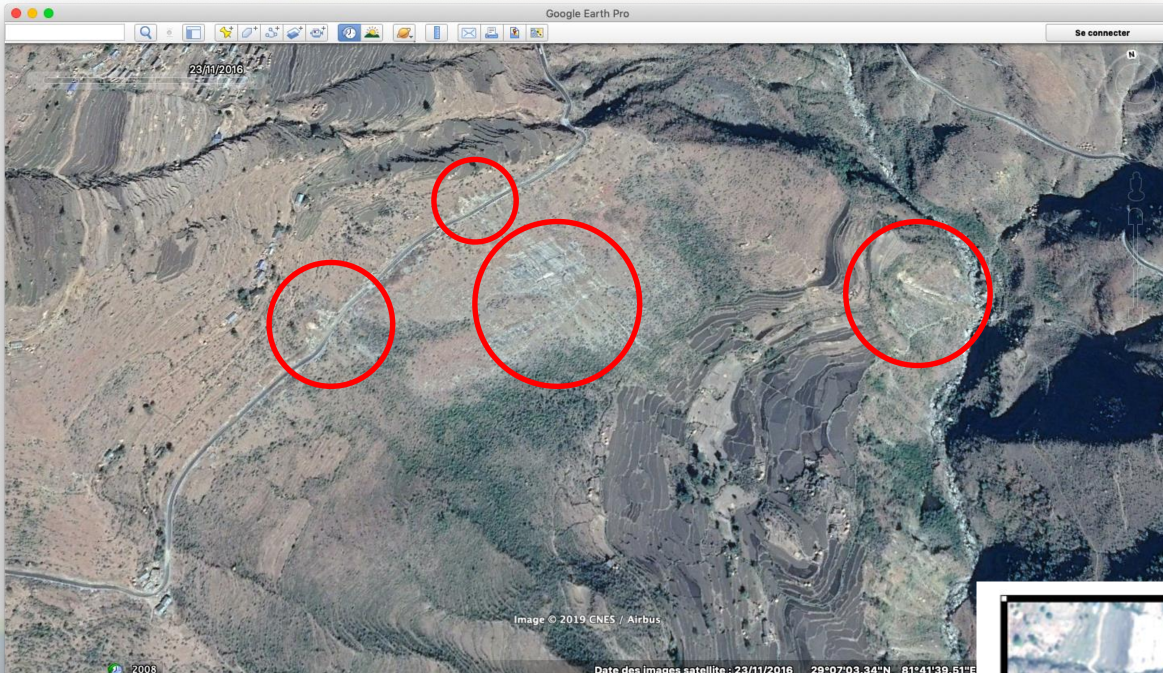
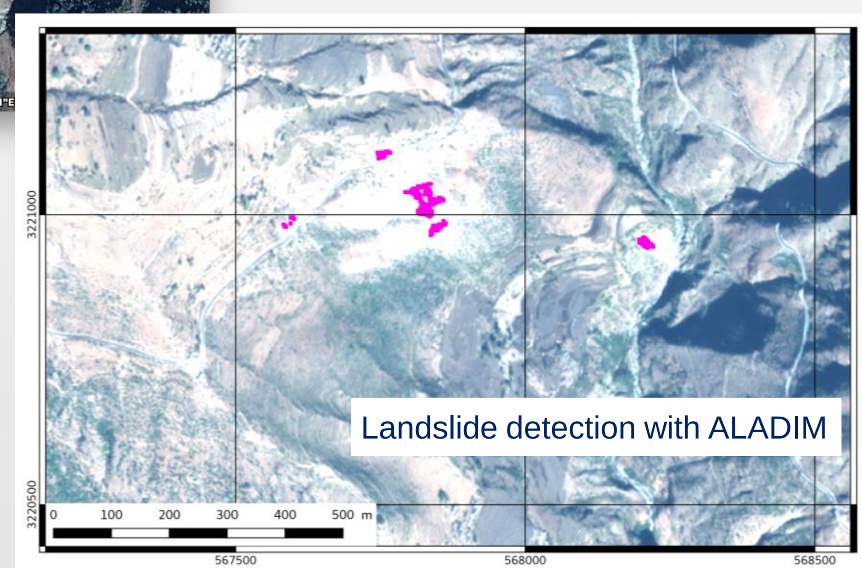
ALADIM SERVICE: AUTOMATIC LANDSLIDE DETECTION AND INVENTORY MAPPING



Landslide area as identified in Google Earth imagery

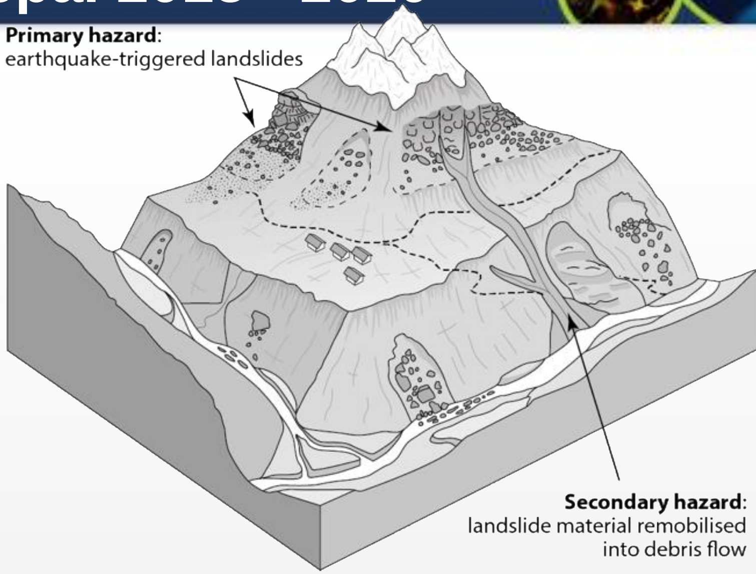


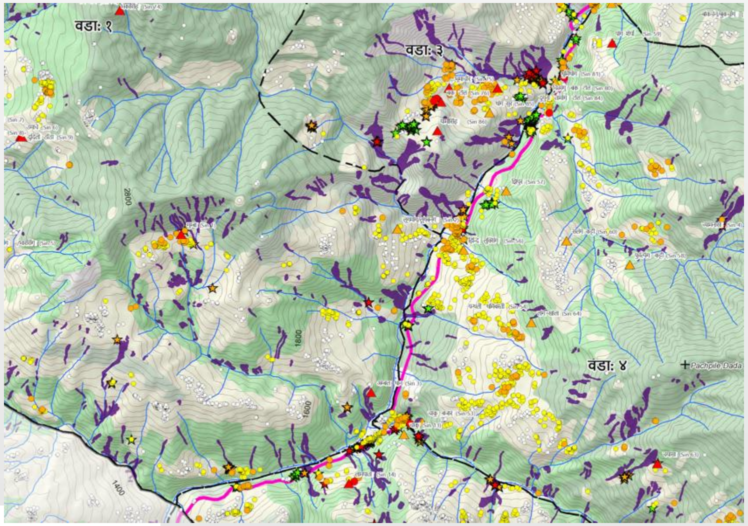
Landslide detection with ALADIM

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

Post-earthquake evolution of landslide hazard & risk from multi-sensor technology: Nepal 2015 - 2020

- **Generation of rolling landslide inventories (>2014) using multi-sensor data (S2, L8, Planets, DG)**
  - Satellite imagery used to generate time series landslide inventory, to landslide change
  - Assess changing hazard across the entire area impacted by 2015 EQ
  - Risk posed by debris flow potential modelled, and assessed for individual households
- **Key findings:**
  - Landslide hazard remains higher today than on the day of the 2015 earthquake
  - 2.5% of households remain currently threatened by landslides (27k)
  - Rural road construction since the 2015 earthquake has had a landslide impact of comparable magnitude to the 2015 earthquake
- **Outputs:**
  - Online GIS interface, for generation of local map products: tinyurl.com/DU-CEOS-Nepal
  - Atlas of 154 local municipality maps, showing individual household-level landslide risk

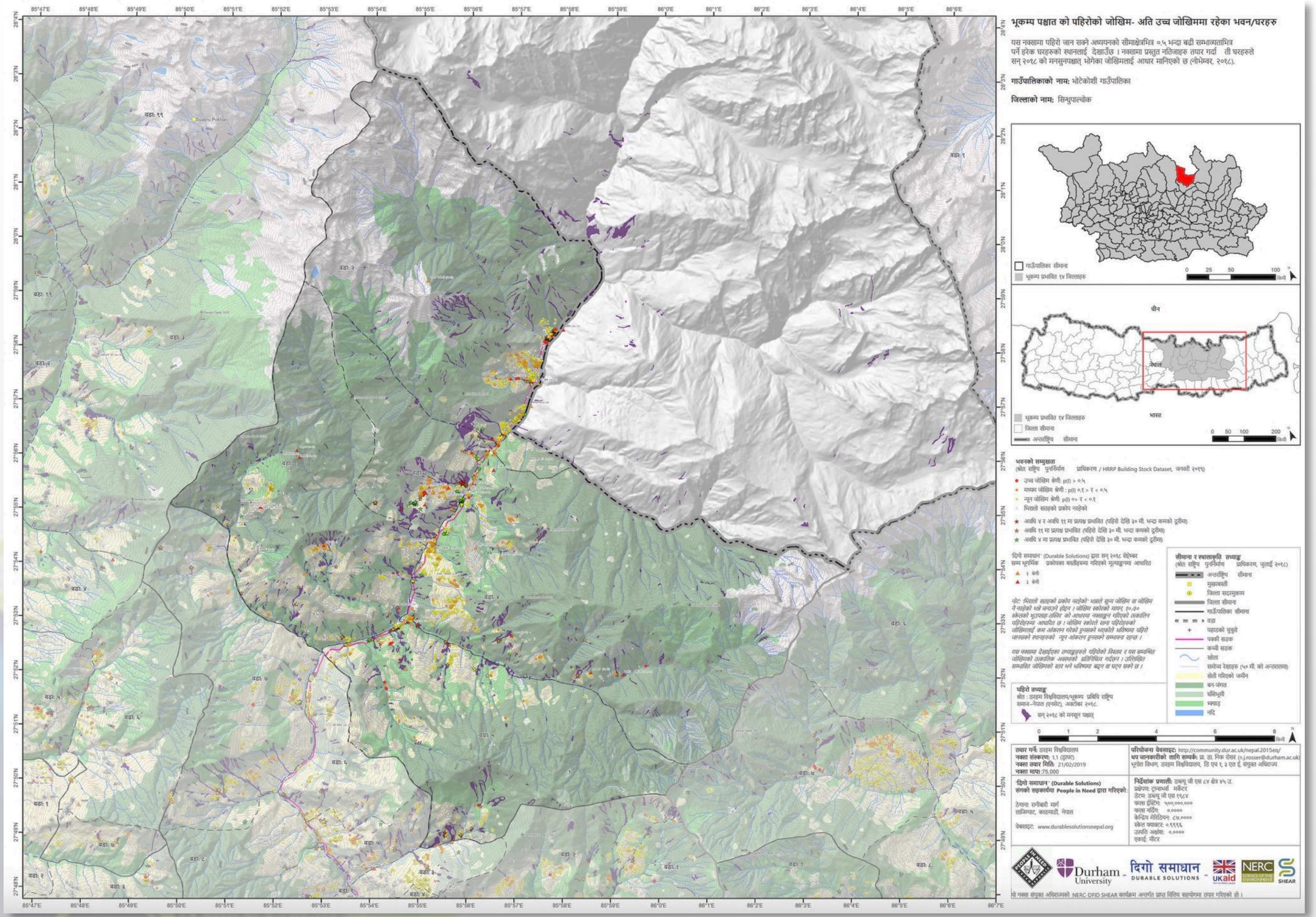




Nick Rosser
(Durham University)

UKaid
Department for International Development
दिगो समाधान
DURABLE SOLUTIONS
NSET
Durham University

Example of generated landslide map



Municipality-level map, showing current landslides, and householder level risk associated with landslide runout

Use of VHRO / Pléiades: BOULDER - Accounting for BOUlders in Landslide-flood hazard Disaster Evaluation and Resilience

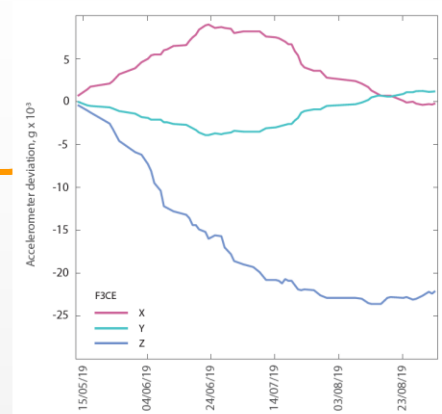
Objectives:

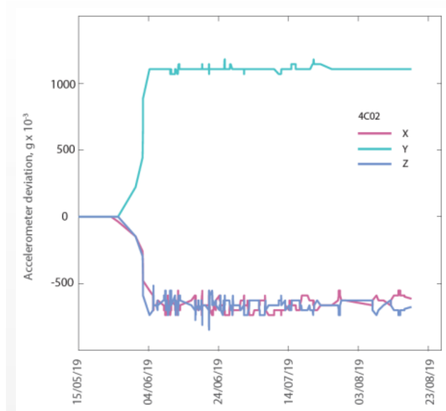
- Develop boulder tracking system
- Understand controls on boulder production on hillslopes
- Towards an early warning system
- Improve resilience through hazard assessment

Phase 1 May 2019: installation of the network
Bhote Koshi, Nepal

23 boulders tagged, sending near real time data

First results





Phase 2 April-May 2020

- Improvement to network configuration
- Refinement of tags programming settings
- Improvement of accelerometer functionality
- Potential addition of gyroscope and magnetometer

University of East Anglia · NERC SCIENCE OF THE ENVIRONMENT · UKaid from the British people · AECOM

Benedicta Dini & Georgina Bennett (Univ. East Anglia)

Use of VHRO / Pléiades: BOULDER - Accounting for BOUlders in Landslide-flood hazard Disaster Evaluation and Resilience

Objectives:

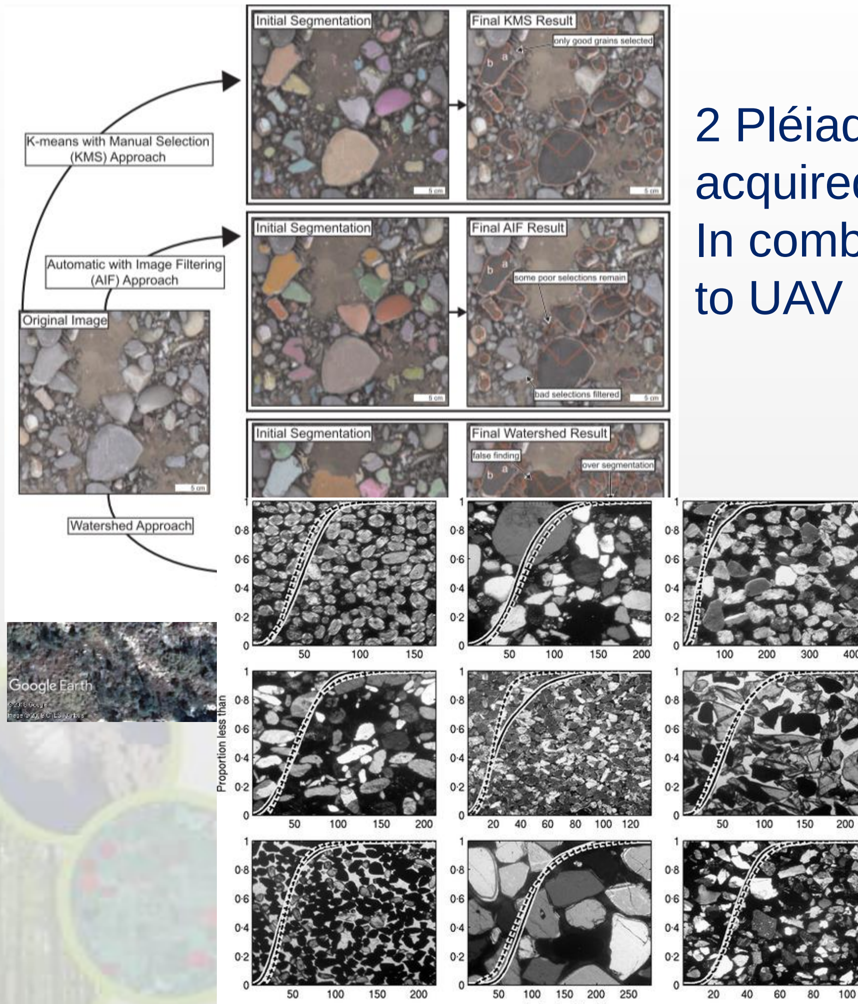
2020

Develop boulder tracking system

Understand controls on boulder production on hillslopes

Towards an early warning system

Improve resilience through hazard assessment



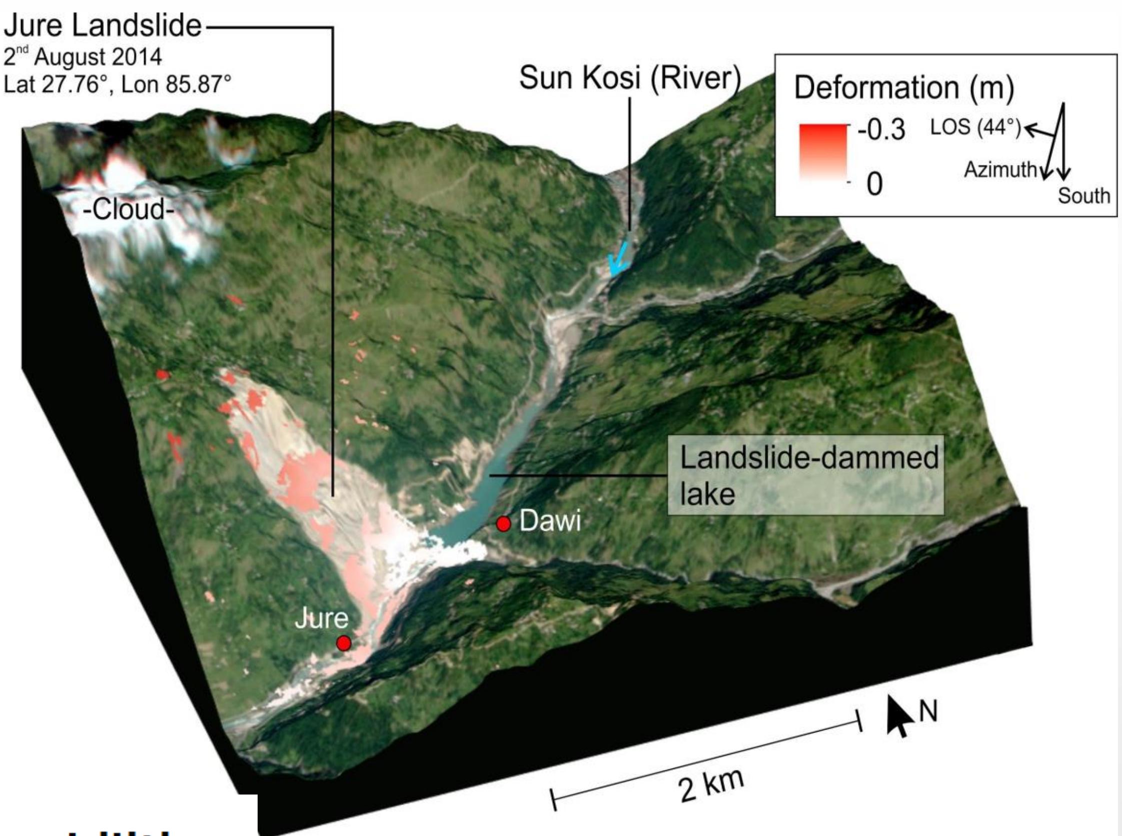
2 Pléiades acquired
In combinatiopn to UAV imagery

Automatic boulder mapping and size distribution from high resolution images

Benedicta Dini & Georgina Bennett (Univ. East Anglia)

Monitoring Jure landslide using CSK data post 2015 EQ, Nepal

On the outcrop of the Jure Landslide scarp, surface deformation of about 0.3 m in line-of-sight (LOS) direction, was measured by stacking three post-seismic InSAR pairs using SBAS analysis.



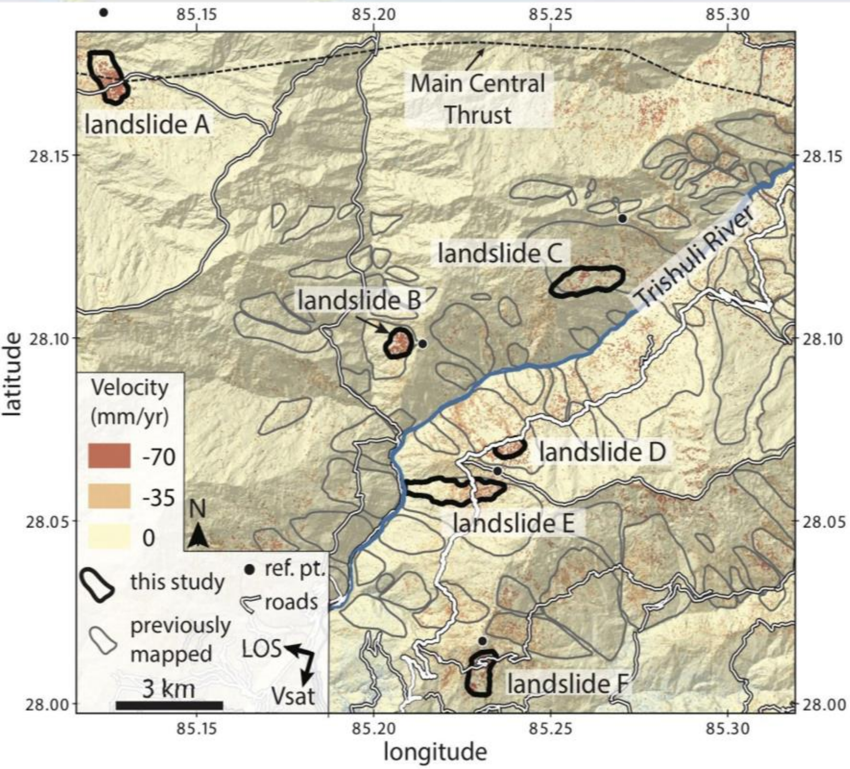
Minjeong Jo(USRA)/Pukar Amatya (USRA)/Dalia Kirschbaum (NASA)

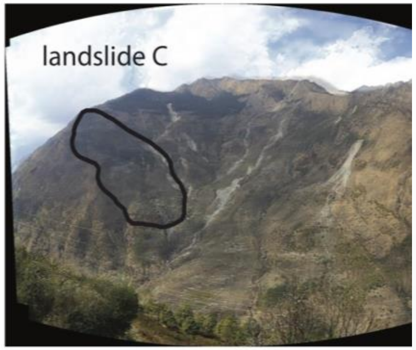
frontiers in Earth Science

The State of Remote Sensing Capabilities of Cascading Hazards Over High Mountain Asia

Dalia Kirschbaum[1*], C. Scott Watson[2], David R. Rounce[3], Dan H. Shugar[4], Jeffrey S. Kargel[5], Umesh K. Haritashya[6], Pukar Amatya[1,7], David Shean[8], Eric R. Anderson[9] and Minjeong Jo[7,10]

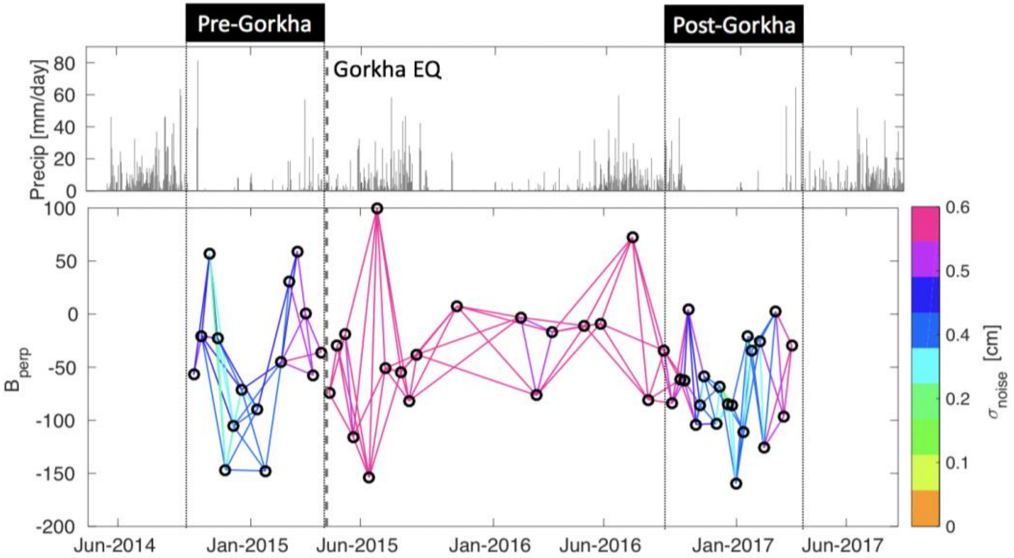
Trishuli Basin Sentinel-1 Slow - moving landslides





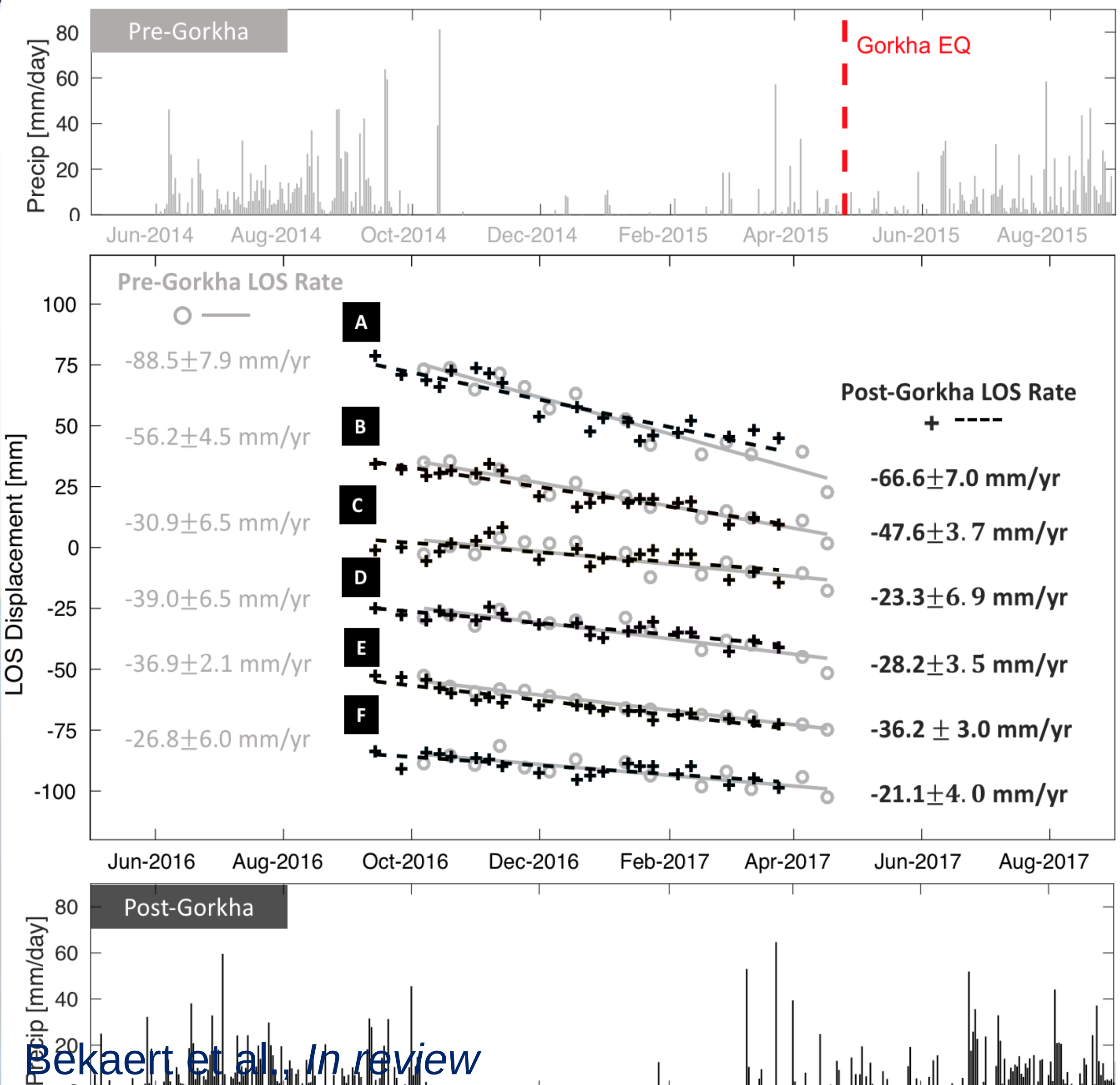
A novel method is developed to detect landslides in mountainous terrain. InSAR time-series is used to identify and monitor slow-moving landslides

Interferogram pairs with colors representing the interferogram phase noise, results show higher phase noise in periods with sparse acquisition density.

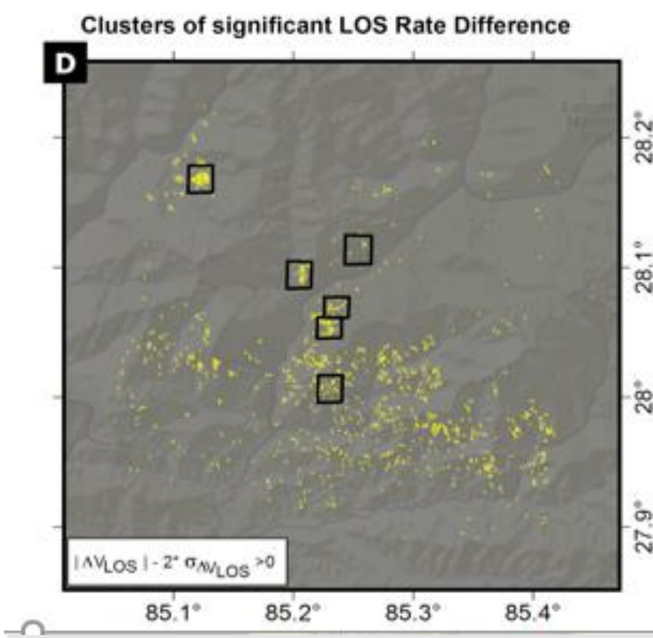


Bekaert et al., *in review*

Trishuli Basin Sentinel-1 Slow moving landslides



6 slow-moving landslides in Trishuli, Nepal appear unaffected by the Gorkha earthquake, with landslides movement likely driven by monsoonal rainfall with rates between 2-9 cm/yr

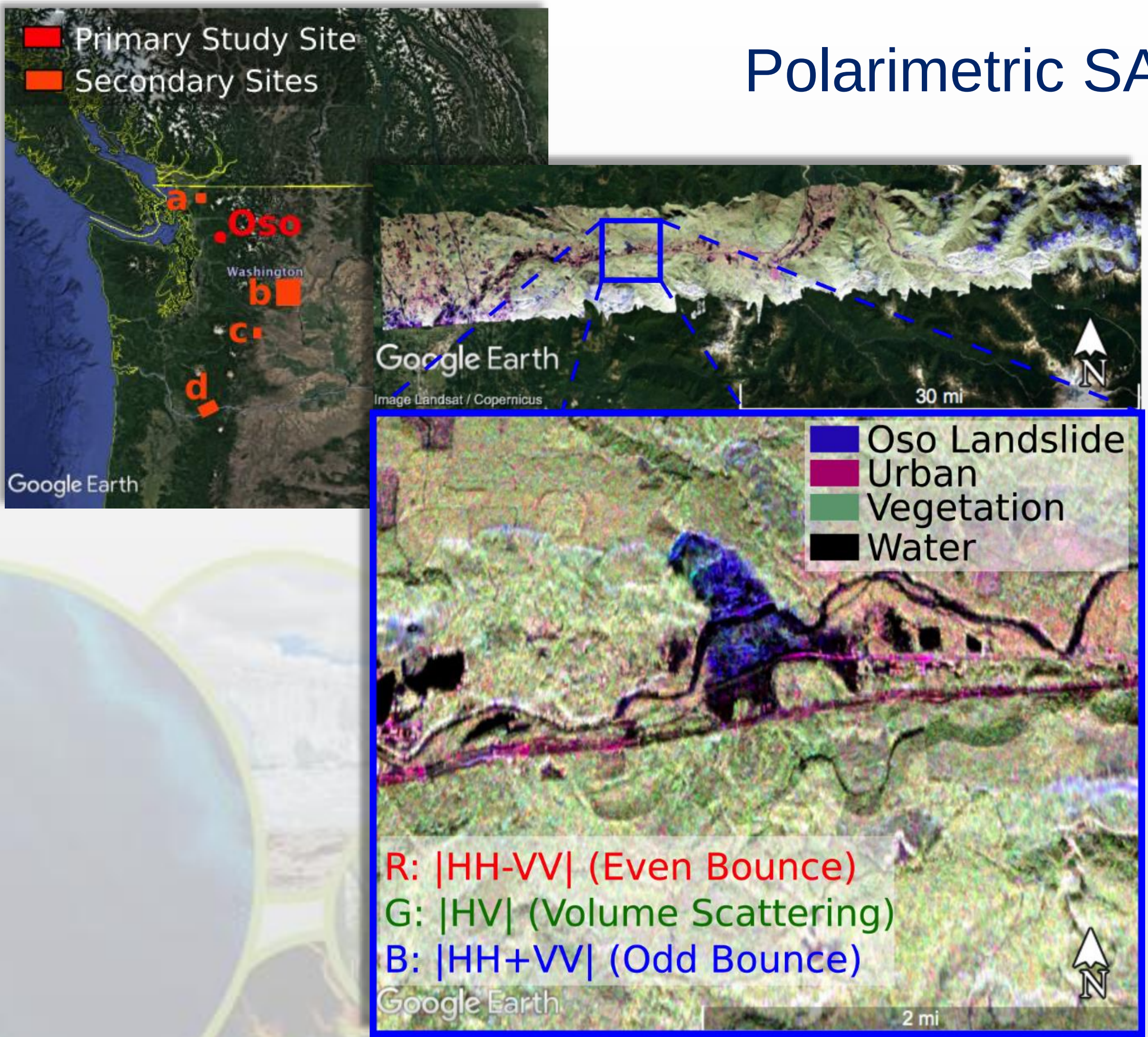


Bekaert et al., *In review*

Pacific Northwest Study Site: Preliminary Results

Landslide mapping by Radar Data

Polarimetric SAR (PolSAR) Approach



Landslide scar was detected for ***Oso Landslide*** in WA using AirMOSS airborne SAR data.

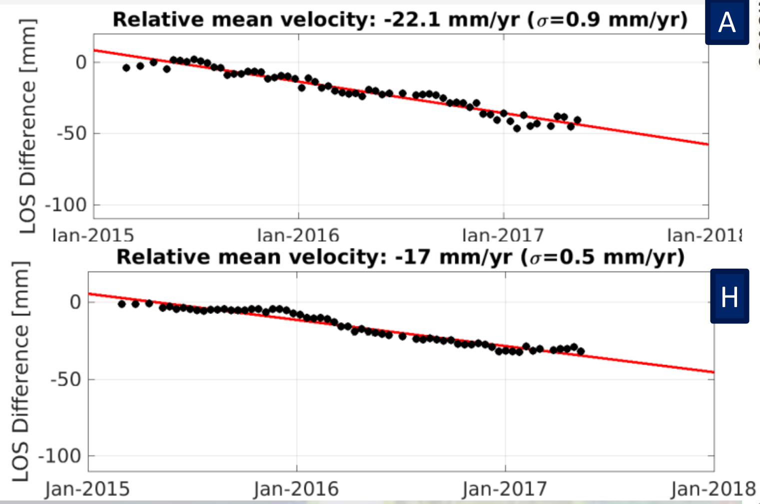
The area in blue show single bounce dominant scattering mechanisms, highlighting the Oso Landslide area.

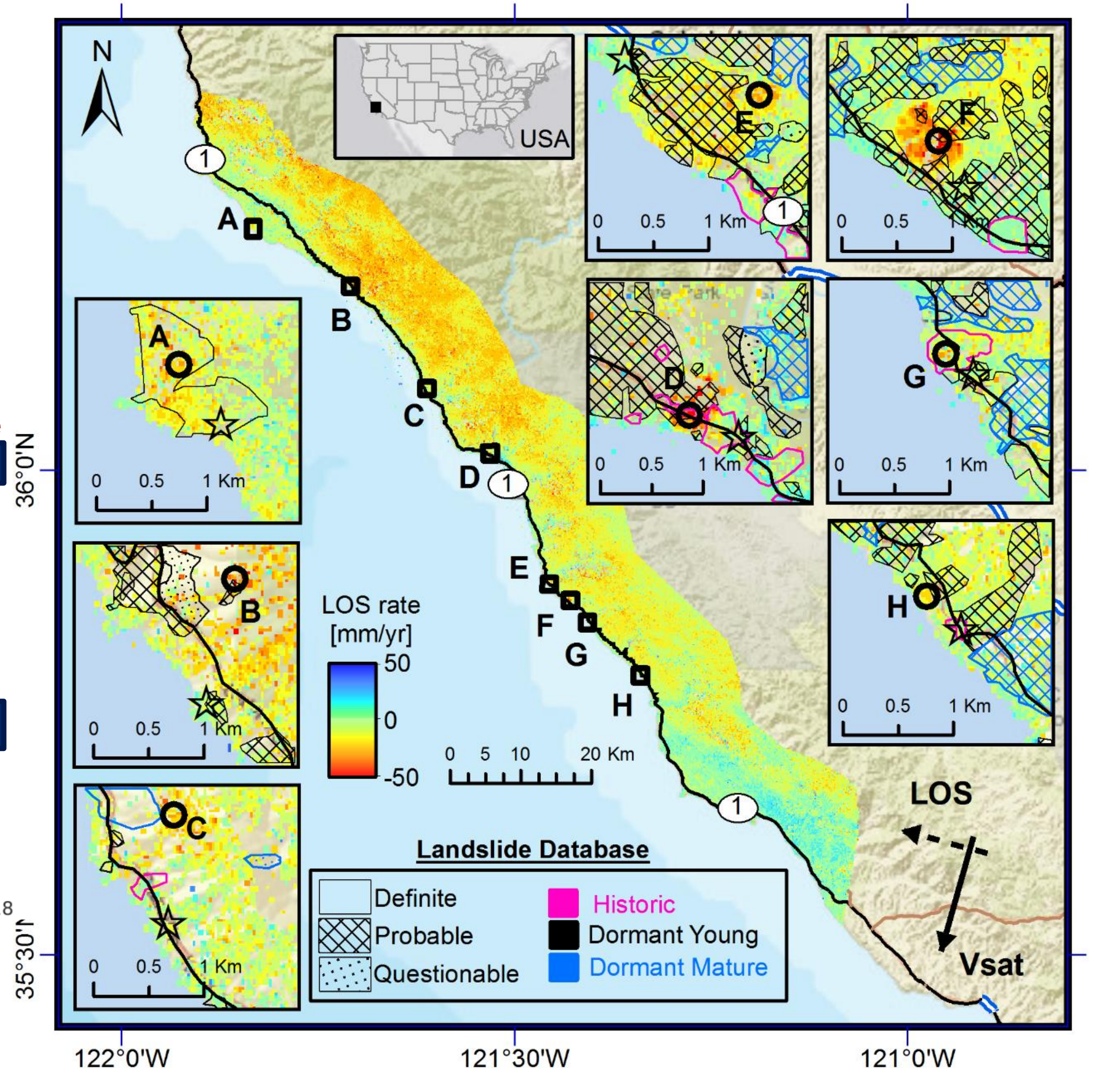
Credit: MinJeong Jo (NASA/USRA)

Time-series InSAR research Demonstration of landslide mapping using Sentinel-1 (PNW, USA)

Map shows average line-of-sight surface displacement rates between Oct 2014-May 2017 using Sentinel 1 SAR data and processed using JPL's ISCE processor and StaMPS time-series package.

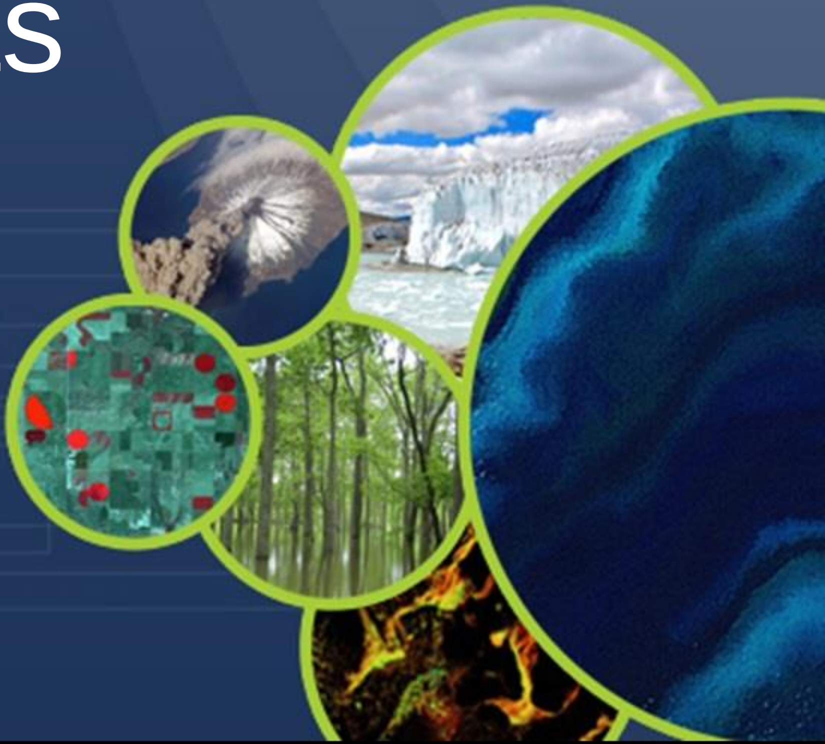
LOS time-series with respect to each reference





D. Bekaert, P. Agram, and H. Fattahi.
(Jet Propulsion Laboratory, California Institute of Technology)

Africa Study Site: Preliminary Results



Regional landslide rainfall thresholds

Use of TRMM/TMPA product:

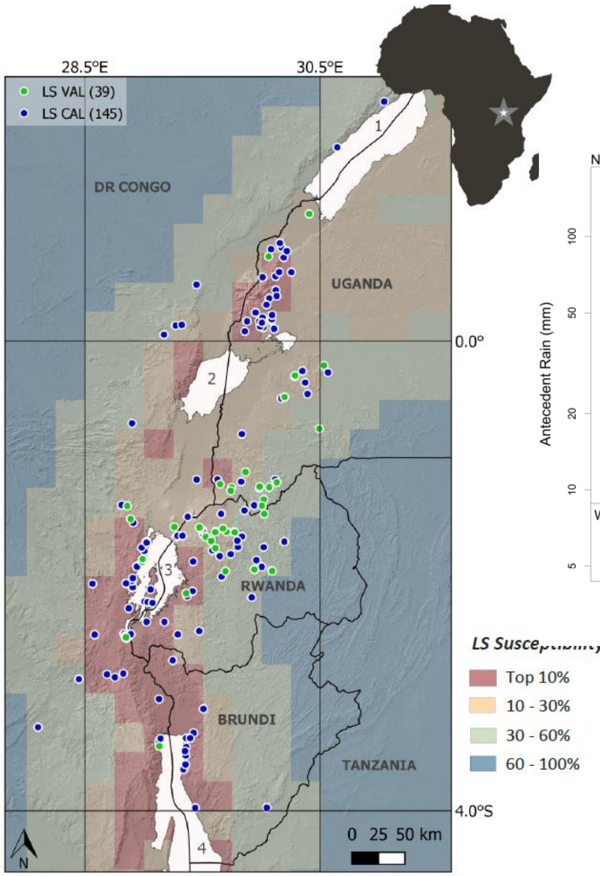
ımprovement of the susceptibility-based rainfall threshold approach for landslide occurrence developed by Monsieurs et al. (NHESS, 2019).

New inputs:

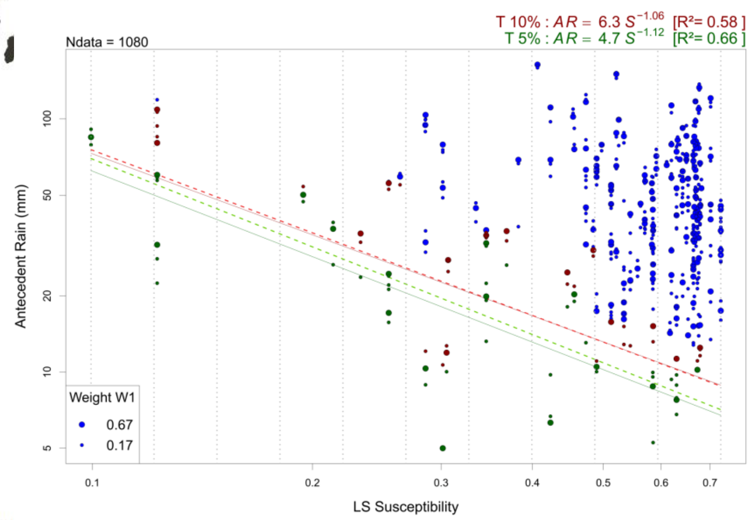
- higher resolution landslide susceptibility
- updated landslide inventory with accurate dates

Key results

- a more robust method that allows better transferability



(b)



Monsieurs et al., to be submitted.

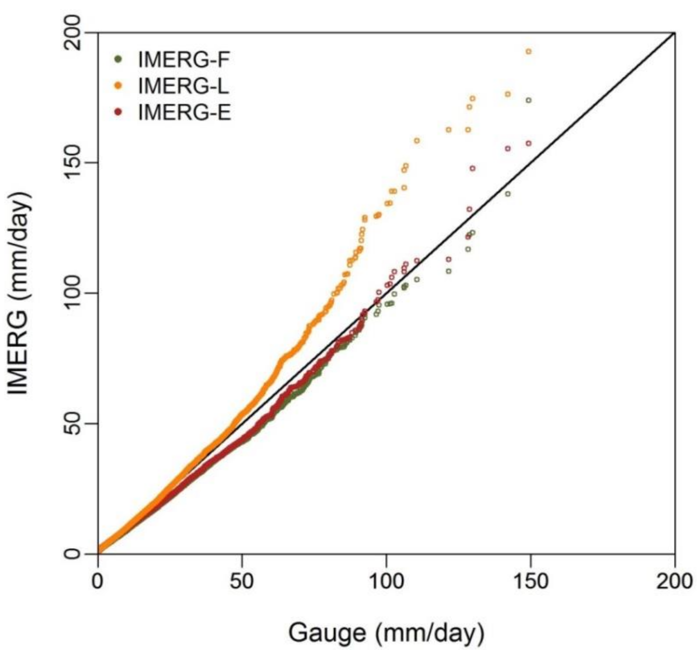
Regional landslide rainfall thresholds

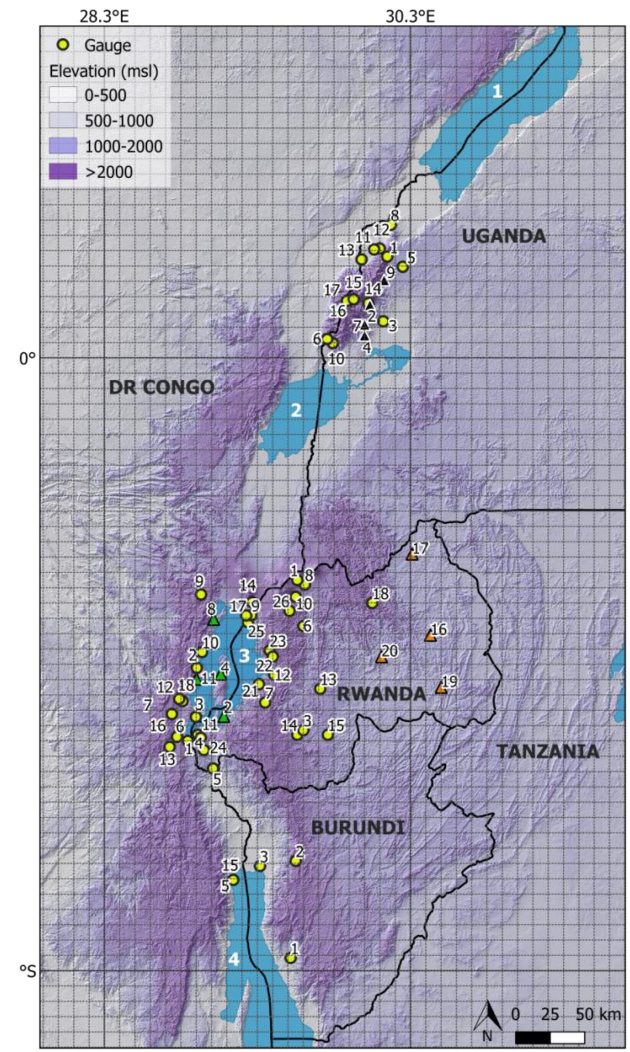
Next step: use of IMERG (work in progress)

In coll. with Dalia Kirschbaum – NASA

Preliminary results:

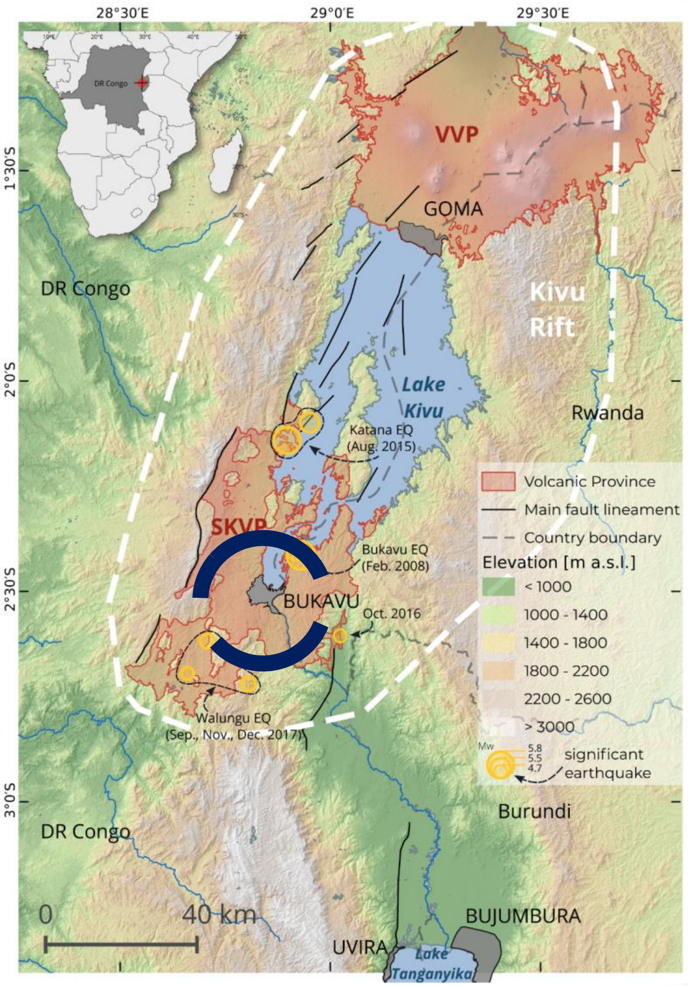
Using the validation method proposed in the Rift by Monsieurs et al. (2018), we show that IMERG performs much better in the region with rainfall estimates very close to rain gauge amounts

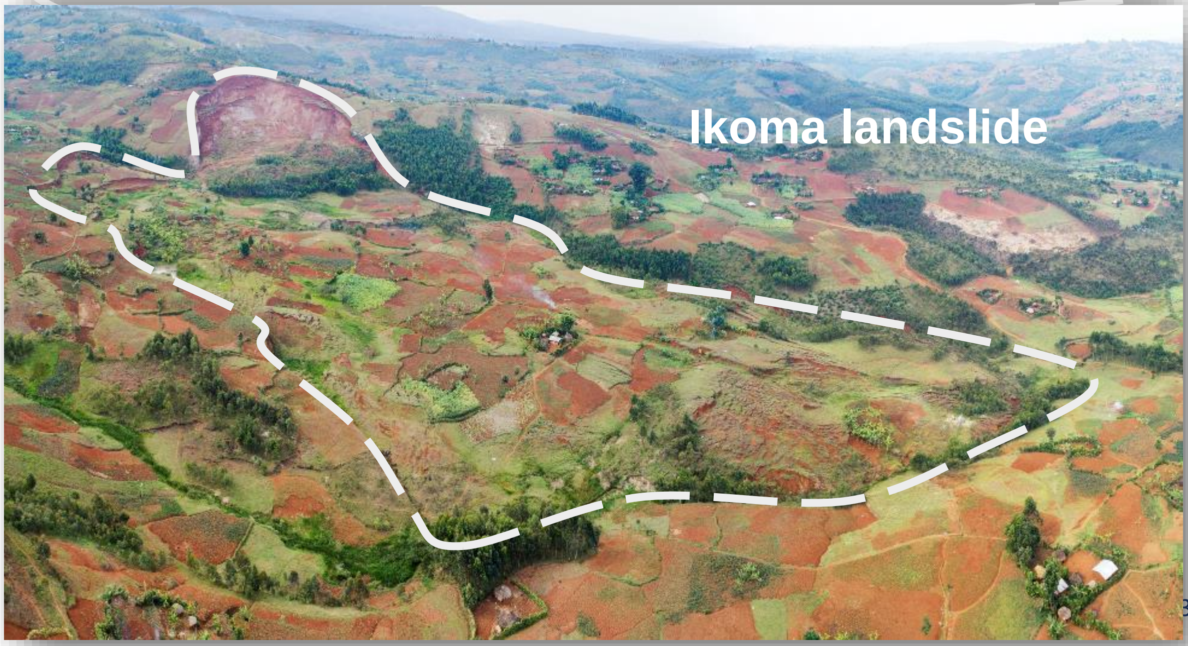




Ground deformations

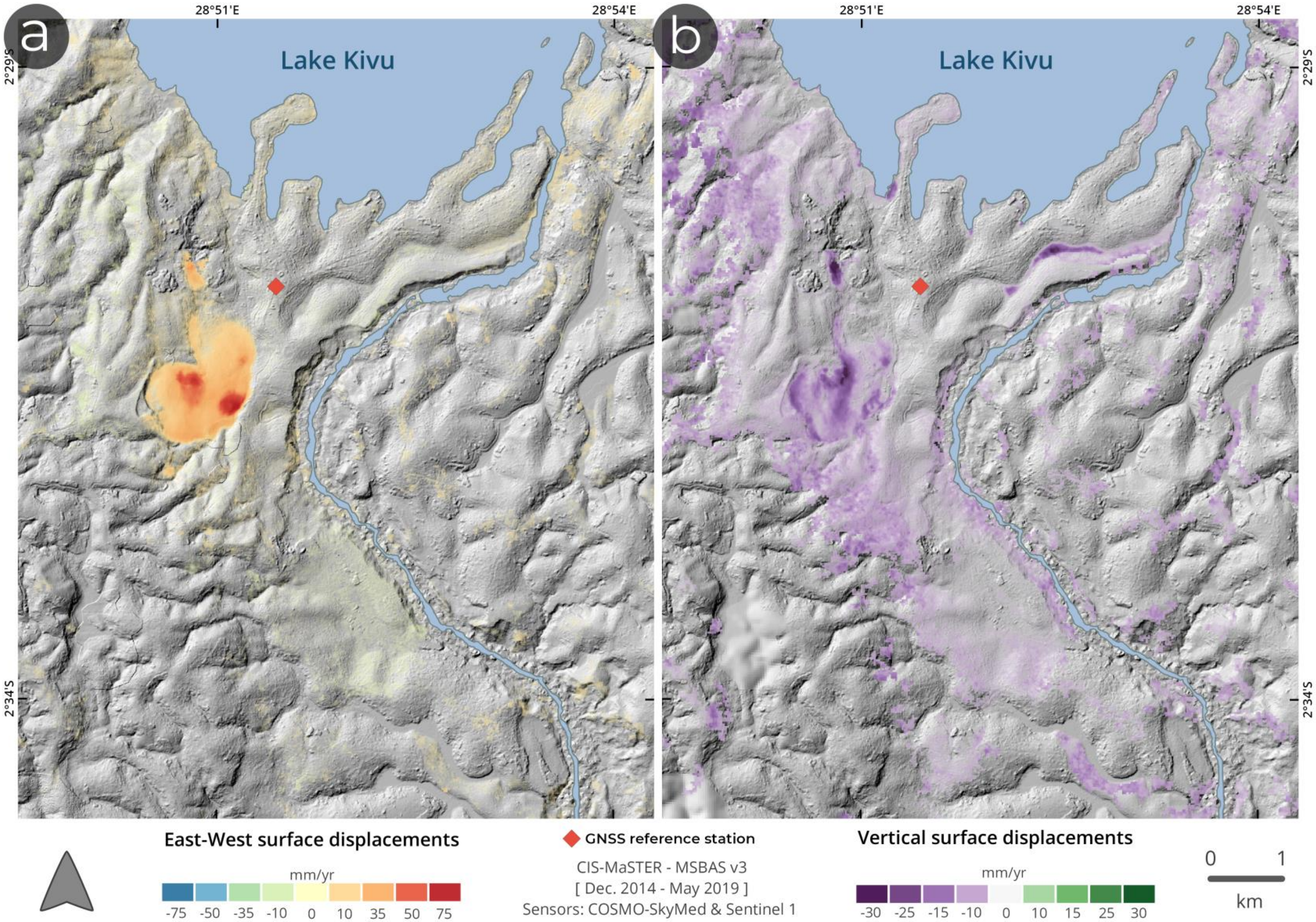
- Focus on the city of Bukavu and its surroundings





Ground deformations

CSK images acquired via CEOS – end in Jan. 2019



Funu landslide

Next steps:

- **Image correlation with Pléiades**
- **Work planned with CNRS/ESOT and GEP**

Dille et al., in prep

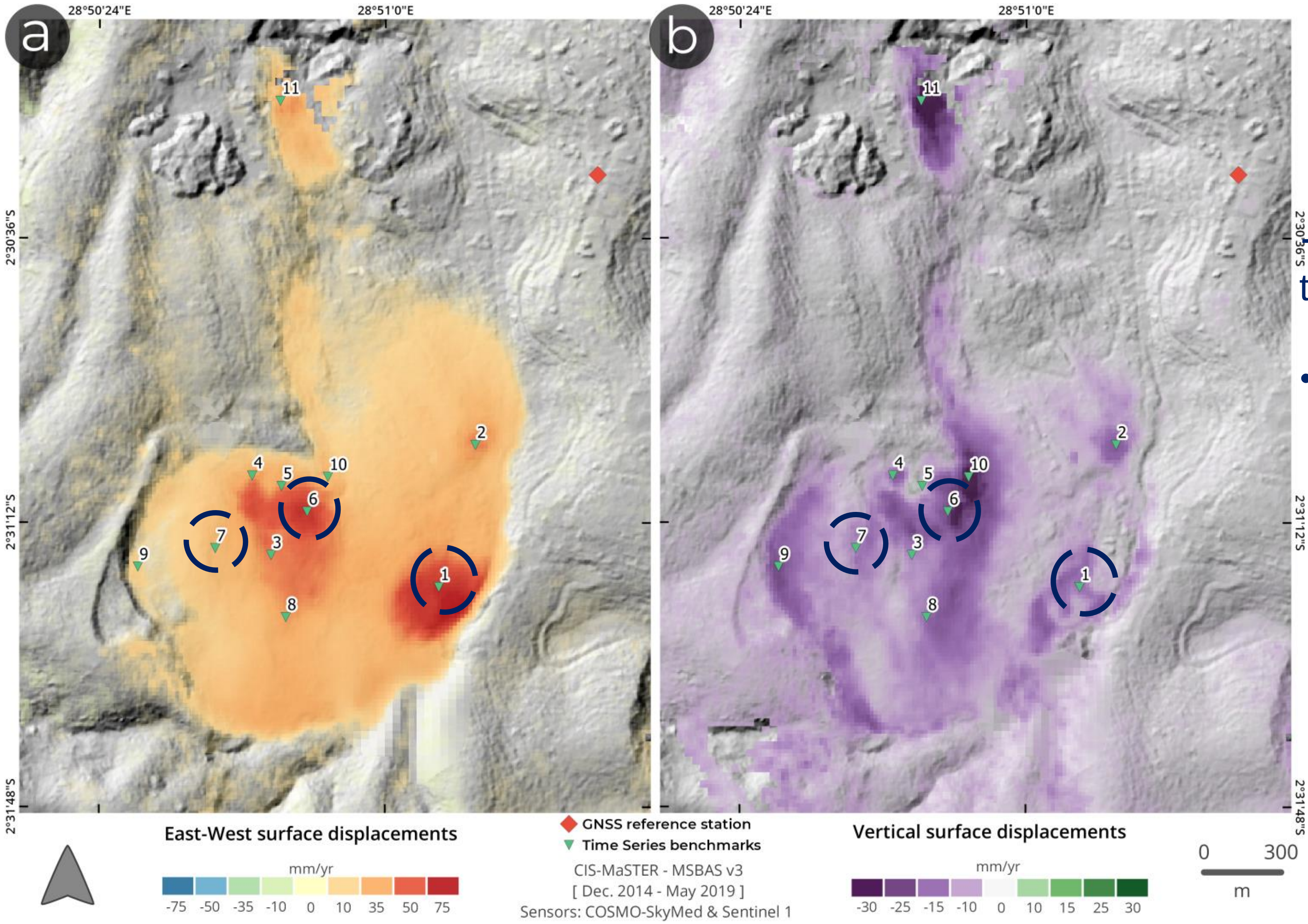
Processing of **>500 CSK and S1 images through MSBAS processing chain**

→ <u>3.5 year time series</u>

MSBAS processing chain
Samsonov and d'Oreye 2012, 2017

Ground deformations

CSK images acquired via CEOS – end in Jan. 2019



→ 4 year deformation time series

- different landslide units with contrasting velocities

Dille et al., in prep

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MSBAS processing chain
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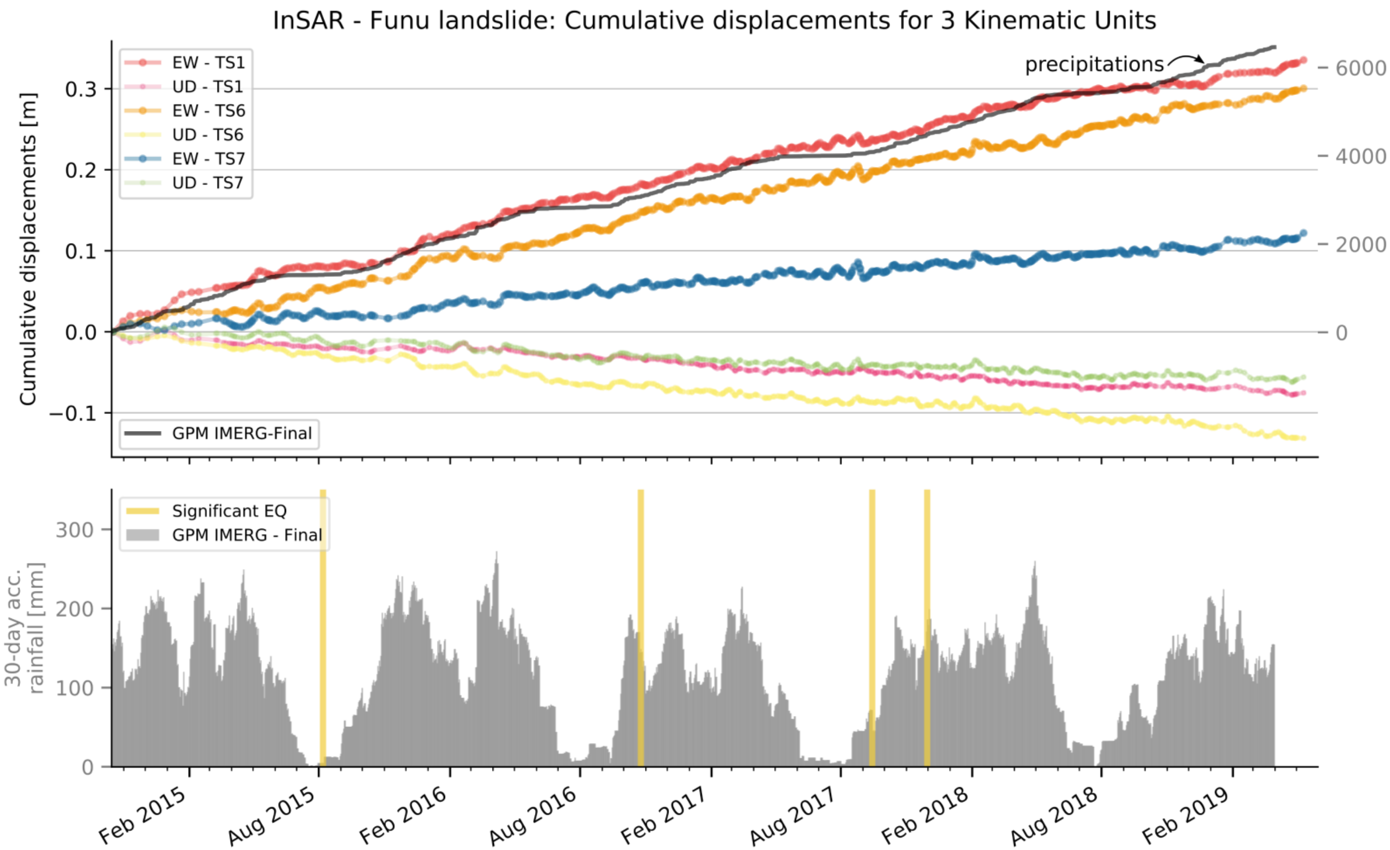

→ 4 year deformation time series

- different landslide units with contrasting velocities
- seasonal control of rainfall on slide behavior

Dille et al., in prep

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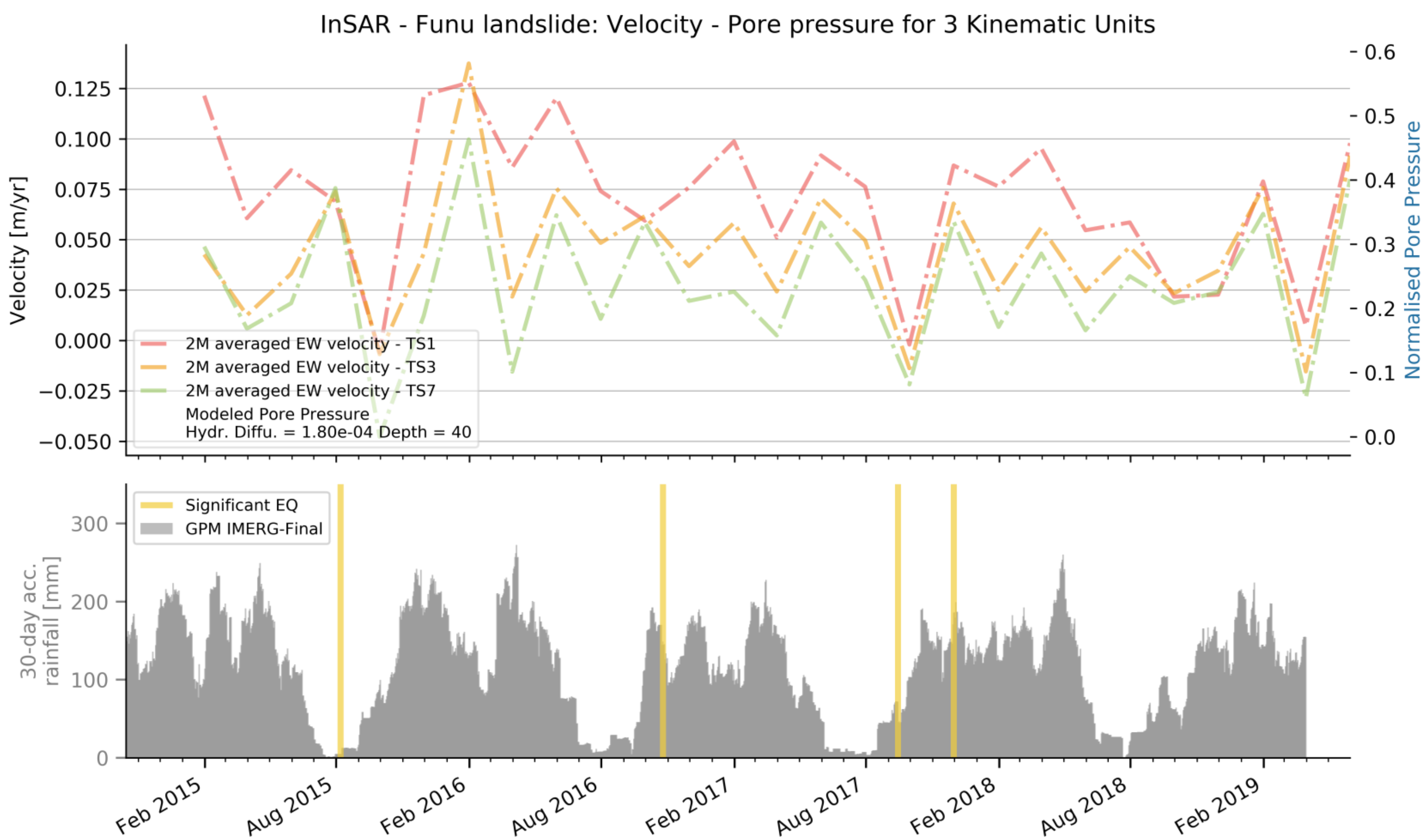

→ 4 year deformation time series

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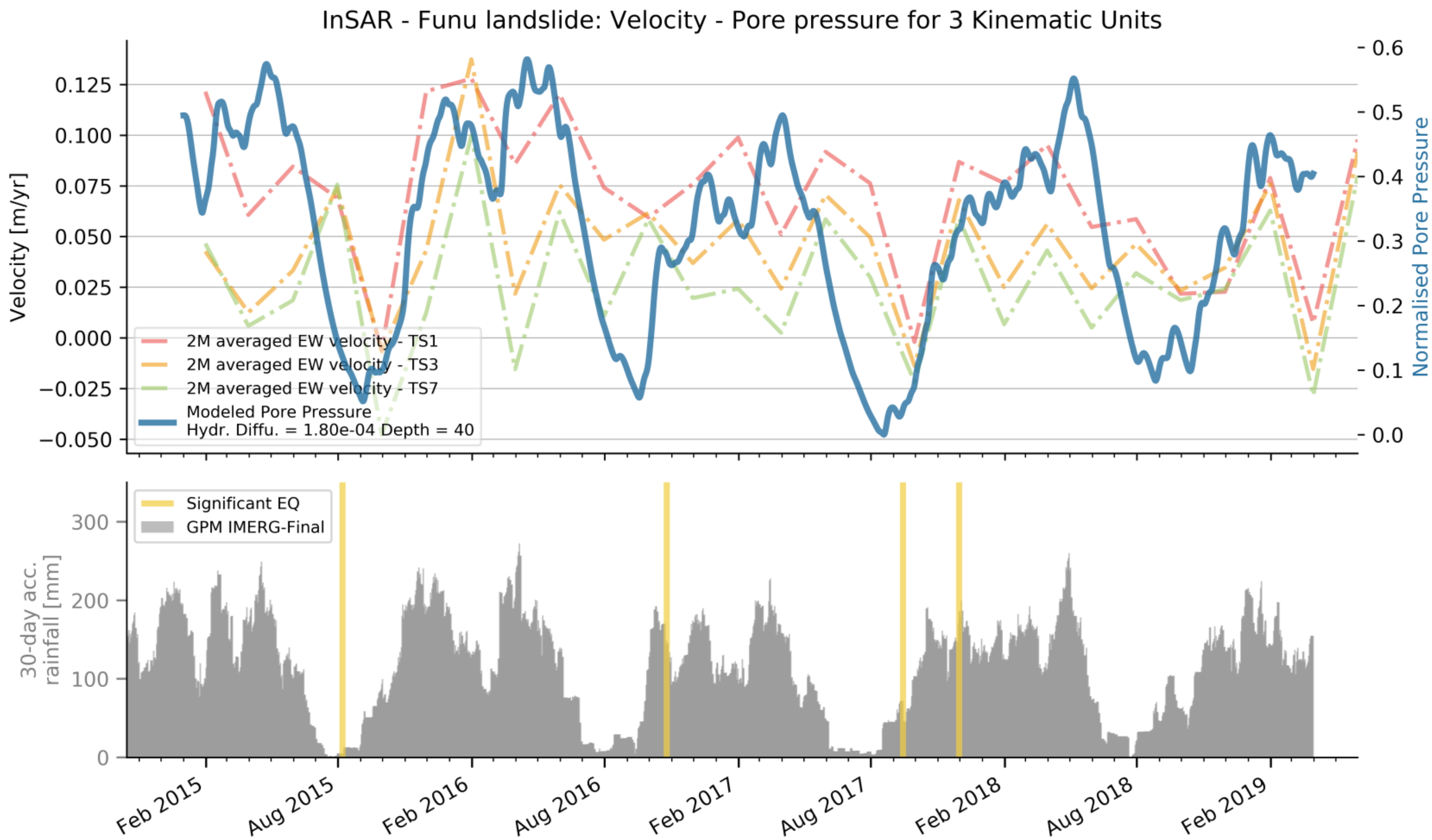
Samsonov and d'Oreye 2012, 2017

Ground deformations

CSK images acquired via CEOS – end in Jan. 2019

In coll. with Alexander Handwerger – NASA/JPL



→ 4 year deformation time series

- different landslide units with contrasting velocities
- seasonal control of rainfall on slide behavior
- very rapid response to rainfall for all landslide units

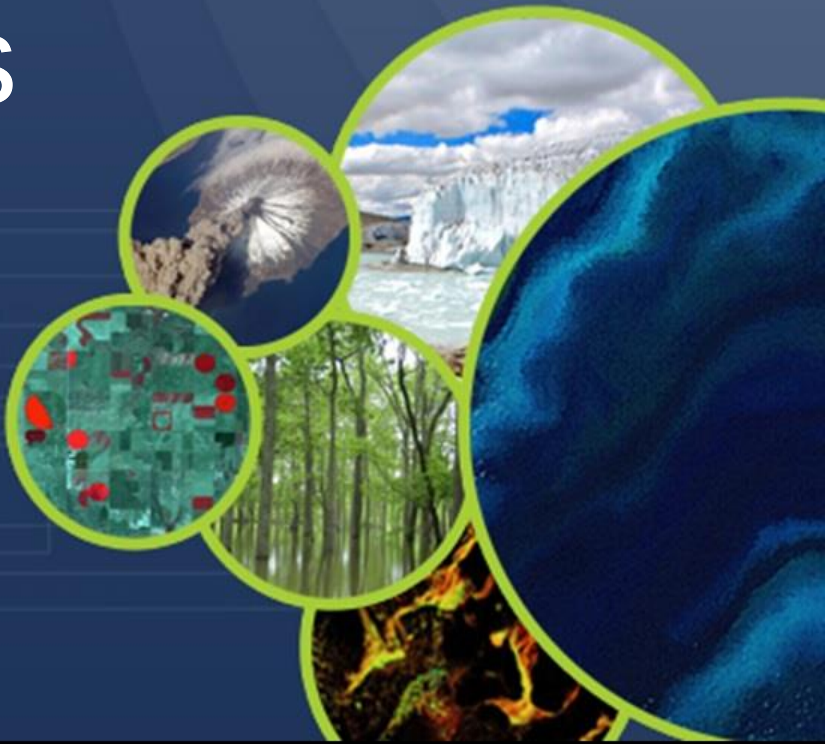
Dille et al., in prep

Processing of **>500 CSK and S1 images through MSBAS processing chain**

→ <u>3.5 year time series</u>

MSBAS processing chain
Samsonov and d'Oreye 2012, 2017

Caribbean Study Site: Preliminary Results



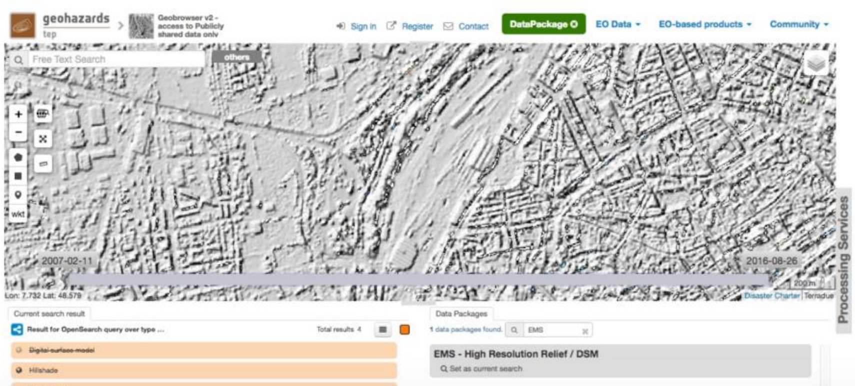
Multi-temporal DSMs from Pléiades imagery to document lahars and geomorphic changes on volcanoes – Use of the DSM-OPT service on GEP

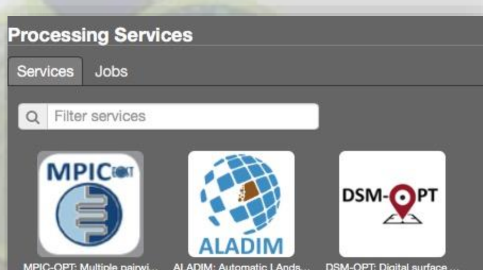
New GEP service from CNRS EOST - DSM-OPT for the generation of surface models from Pléiades satellite data

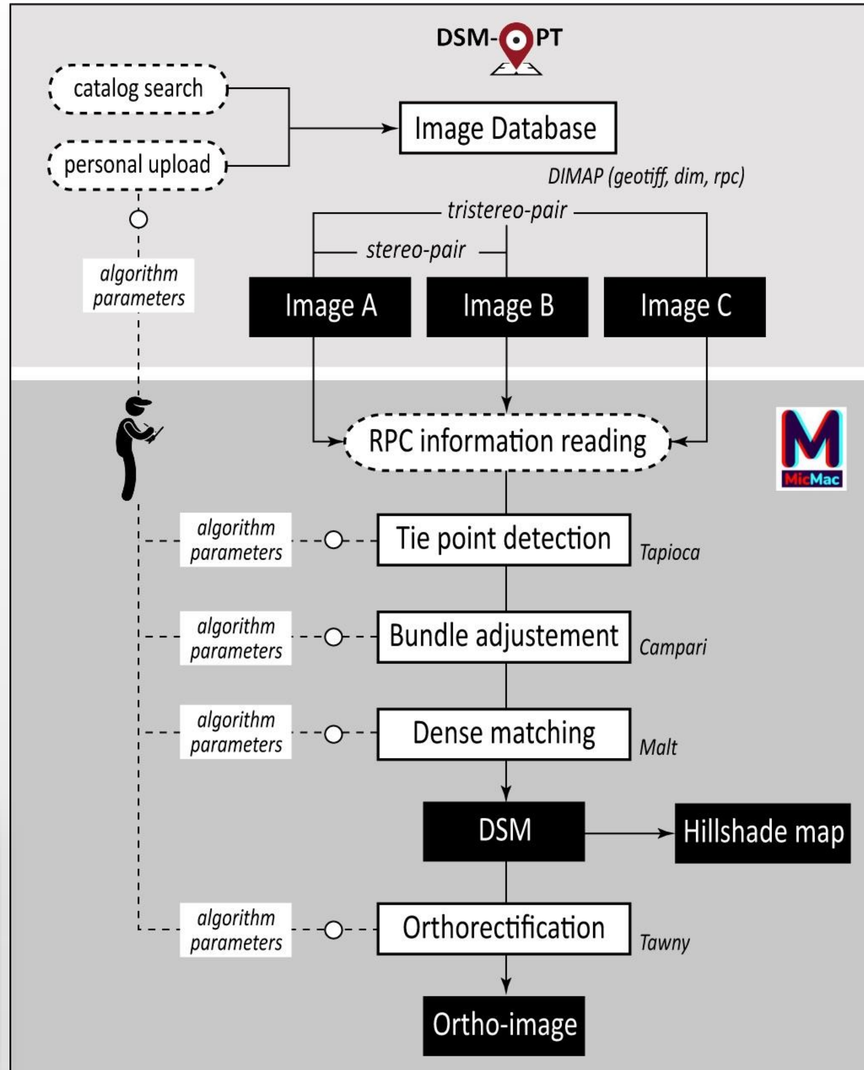
gep-blog

jeanphilippe.malet 1 Mar 5

You need a high resolution surface model to analyse the traces of a fault rupture, to calculate the elevation differences (depletion, accumulation) following a large landslide, to estimate the volume of lava flows on volcanoes and estimate effusive rates, or integrate an accurate topography in InSAR processing? The new GEP service DSM-OPT from CNRS-EOST 8 is for you! This service allows the generation of digital surface models (DSMs) and the respective ortho-images from stereo- and tri-stereo Pléiades images using the MicMac 6 open source library 4.
An example of the service results using stereo-images over the complex urban landscape of Strasbourg is presented below, and is also posted here 4.

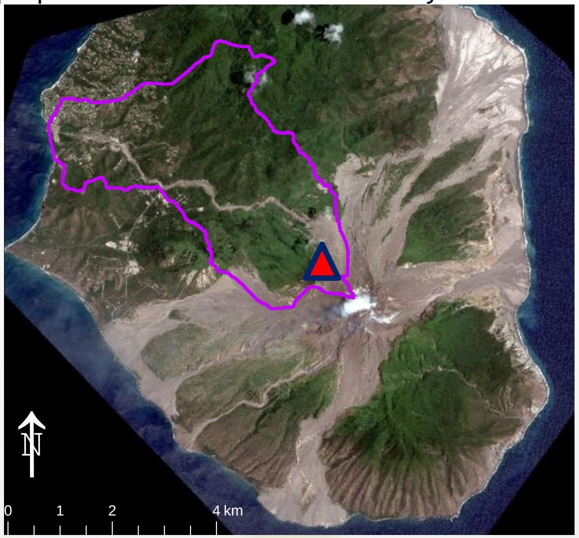






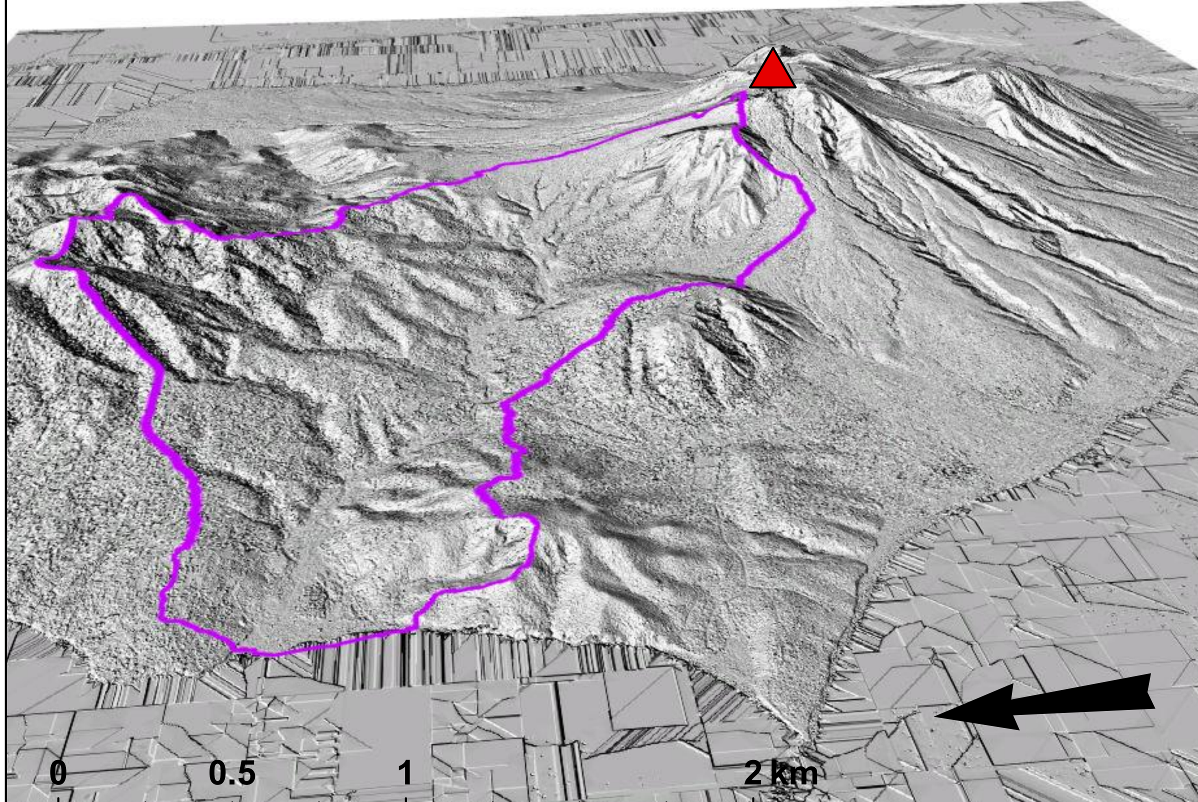
Soufriere Hills Volcano: DSM generation (DSM-OPT) from Pléiades tri-stereo imagery for post-eruption lahars change detection

Pléiades image of Soufriere Hills Volcano, 2017, purple outline shows Belham Valley Catchment;



- Significant deposition of volcaniclastic material in The Belham River Valley between 1995–2010 as a result of explosive eruption
- Channel prone to hazardous rain-triggered lahars and associated geomorphic changes
- Understand how the valley has evolved in the time (now 9 years) following the cessation of volcanic activity in 2010.
- Our new 2019 DSM will be compared with a LIDAR DSM made in 2010 to quantify erosion and deposition in different parts of the valley.

University of East Anglia
MVO Montserrat Volcano Observatory
ENV EAST Doctoral Training Partnership

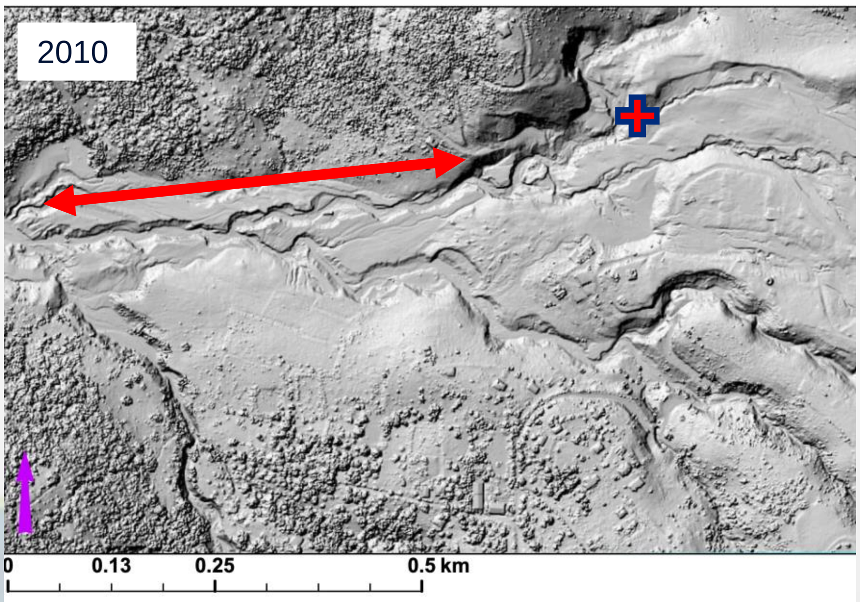


Oblique view from the west of DSM generated with tri-stereo Pleiades images from March 2019, processed using DSM-OPT. Purple outline = Belham Valley

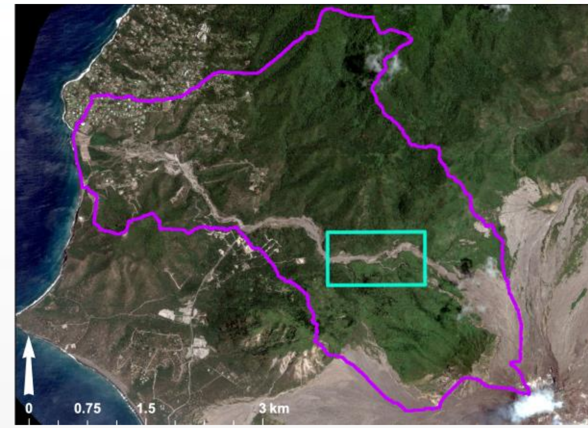
James Christie & Georgina Bennett (Univ. East Anglia)

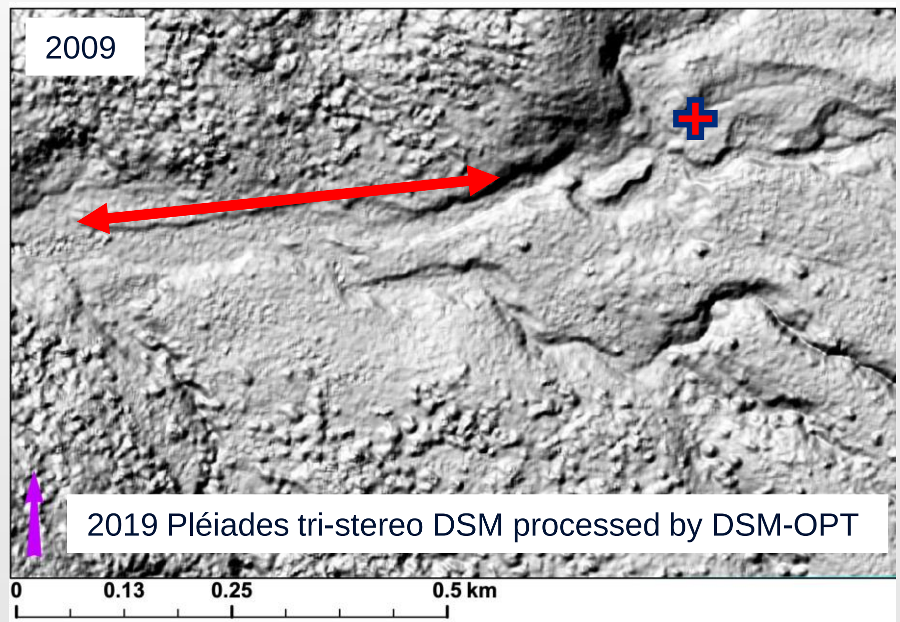
Soufriere Hills Volcano: DSM generation (DSM-OPT) from Pléiades tri-stereo imagery for post-eruption lahars change detection

2010 1m LiDAR DSM (*Montserrat Volcano Observatory)*



Area shown in the example target areas below (green box)





Qualitative observations:

- Channel widening and straightening (removal of pyroclastic terraces)
- Deep channel incision and increased sinuosity.

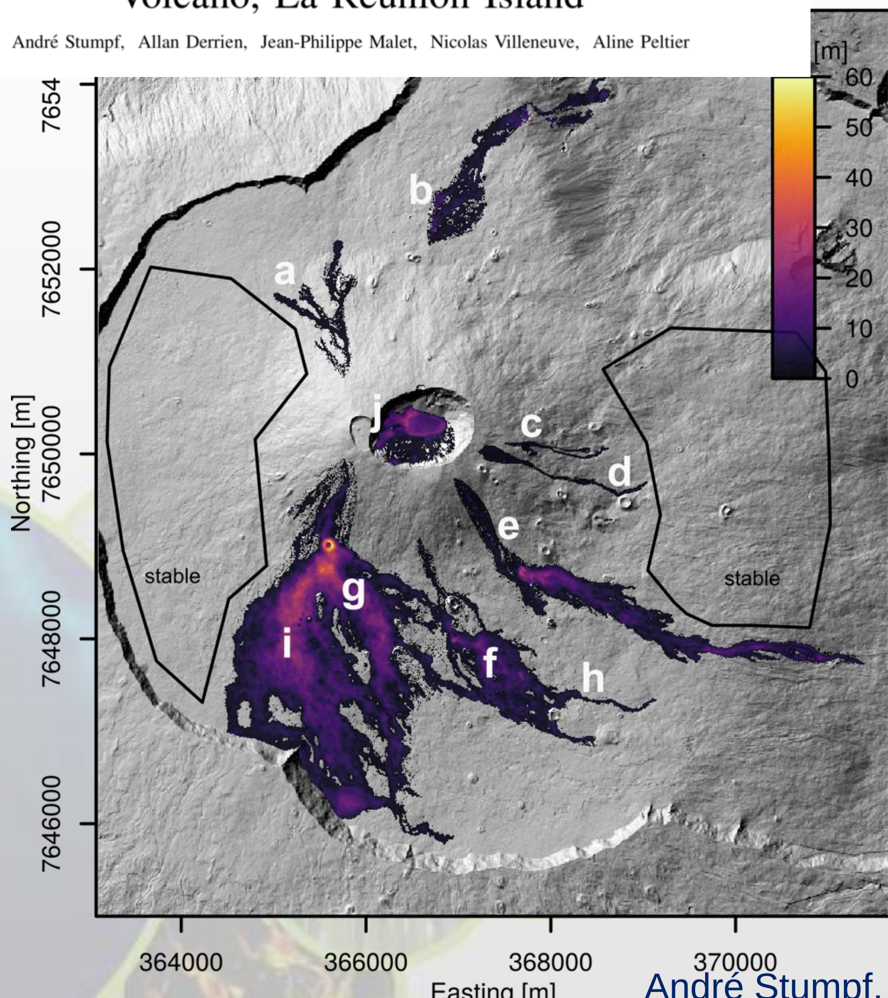
James Christie & Georgina Bennett (Univ. East Anglia)

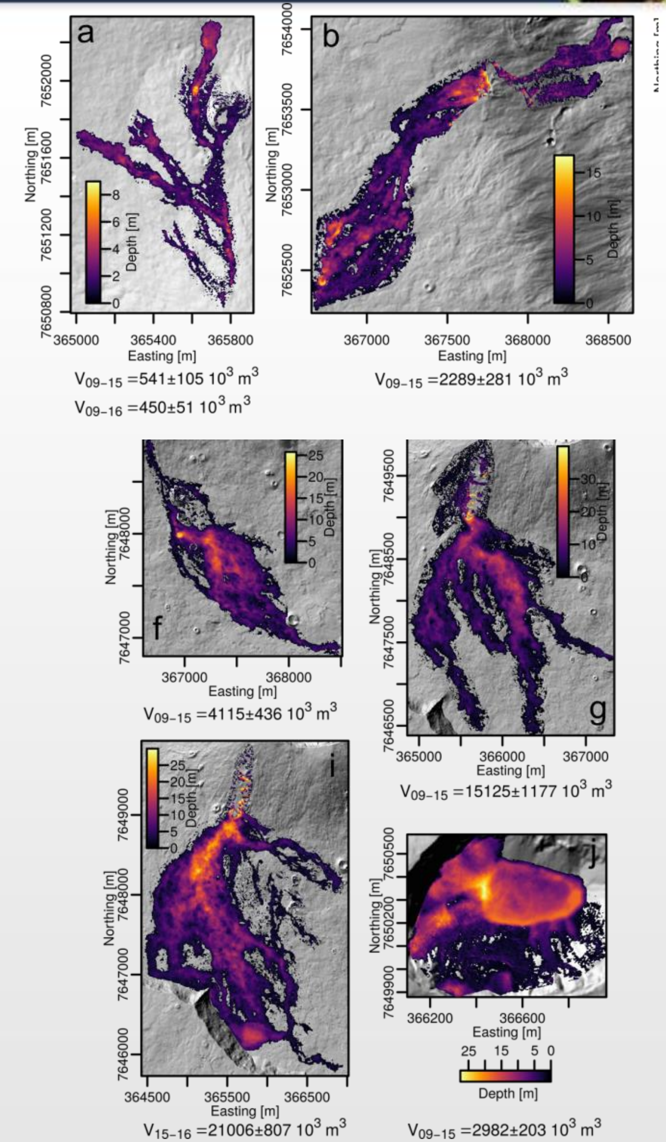
La Réunion Island – Piton de la Fournaise Volcano: multi-date DSM generation (DSM-OPT) from Pléiades tri-stereo imagery for lava flow volumes estimation

IEEE GEOSCIENCE AND REMOTE SENSING LETTERS 1

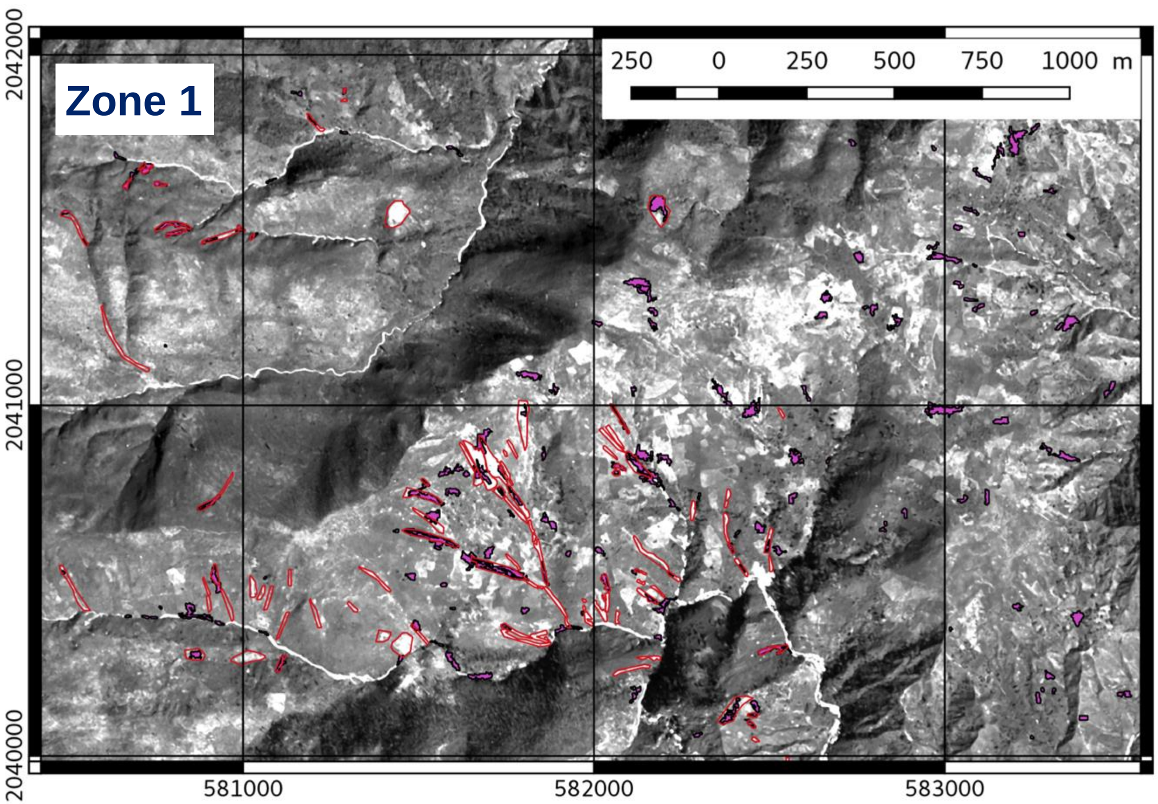
High Resolution Satellite Photogrammetry for Lava Flow Volume Estimation at Piton de la Fournaise Volcano, La Réunion Island

André Stumpf, Allan Derrien, Jean-Philippe Malet, Nicolas Villeneuve, Aline Peltier





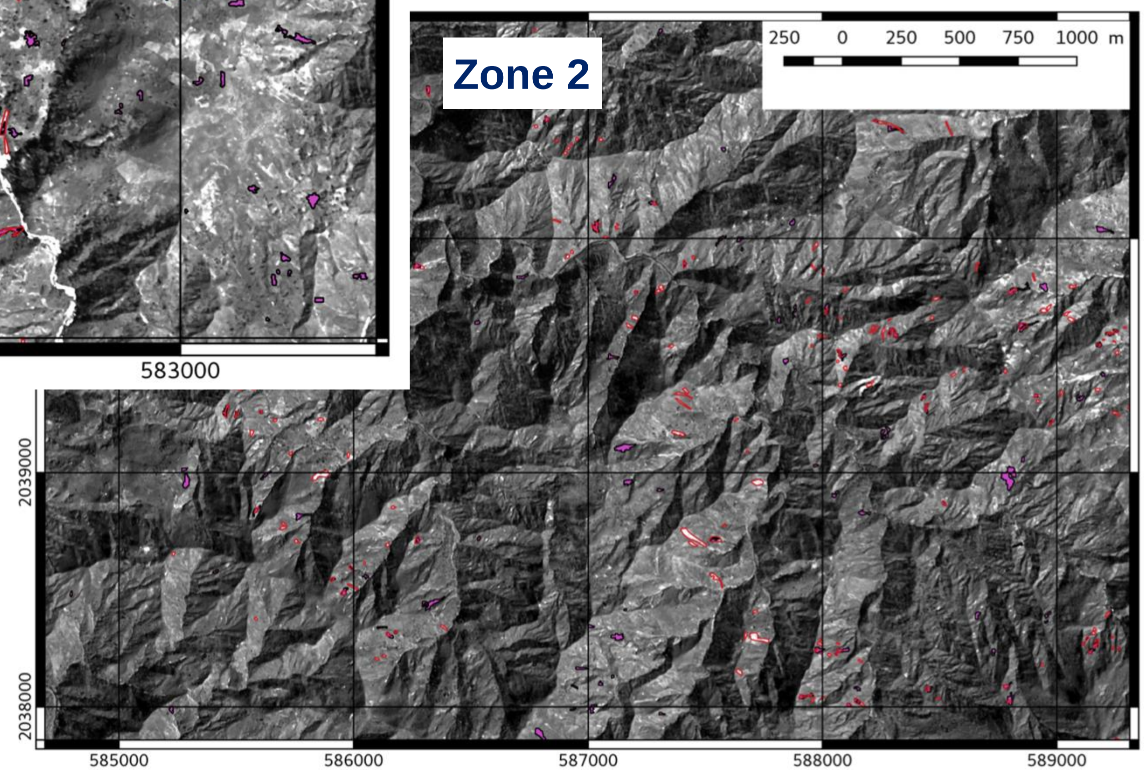
LANDSLIDE DETECTION WITH ALADIM: RAIN-TRIGGERED LANDSLIDES HURRICANE MATTHEWS - HAITI



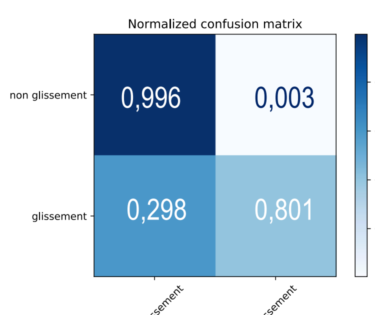
Machine Learning with 20 attributes

Parameters:

SEG_SCALE=120 ; SEG_COLOR_WEIGHT=0.9
SEG_SHAPE_WEIGHT=0.1 ; SEG_N_FIRSTITER=9
SEG_MIN_SIZE=3 ; SUN_AZIMUTH=90.44,31.17
SUN_ELEVATION=64.28,40.22 ;
POSITIVE_THRESHOLD=0.5 ; USE_CLOUD_MASK=True



Accuracy:
Confusion matrix

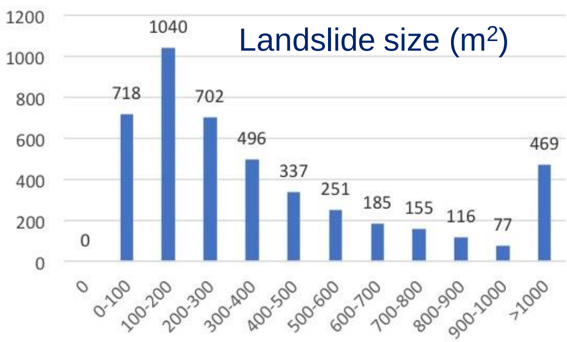


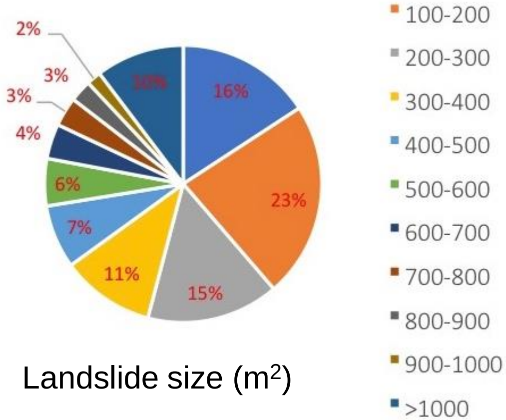
Aline Déprez & Jean-Philippe Malet (CNRS/EOST)

USE OF EO-DERIVED LANDSLIDE INVENTORY: STATISTICS AND TRIGGERS FOR FORECAST

Aggregated indicators

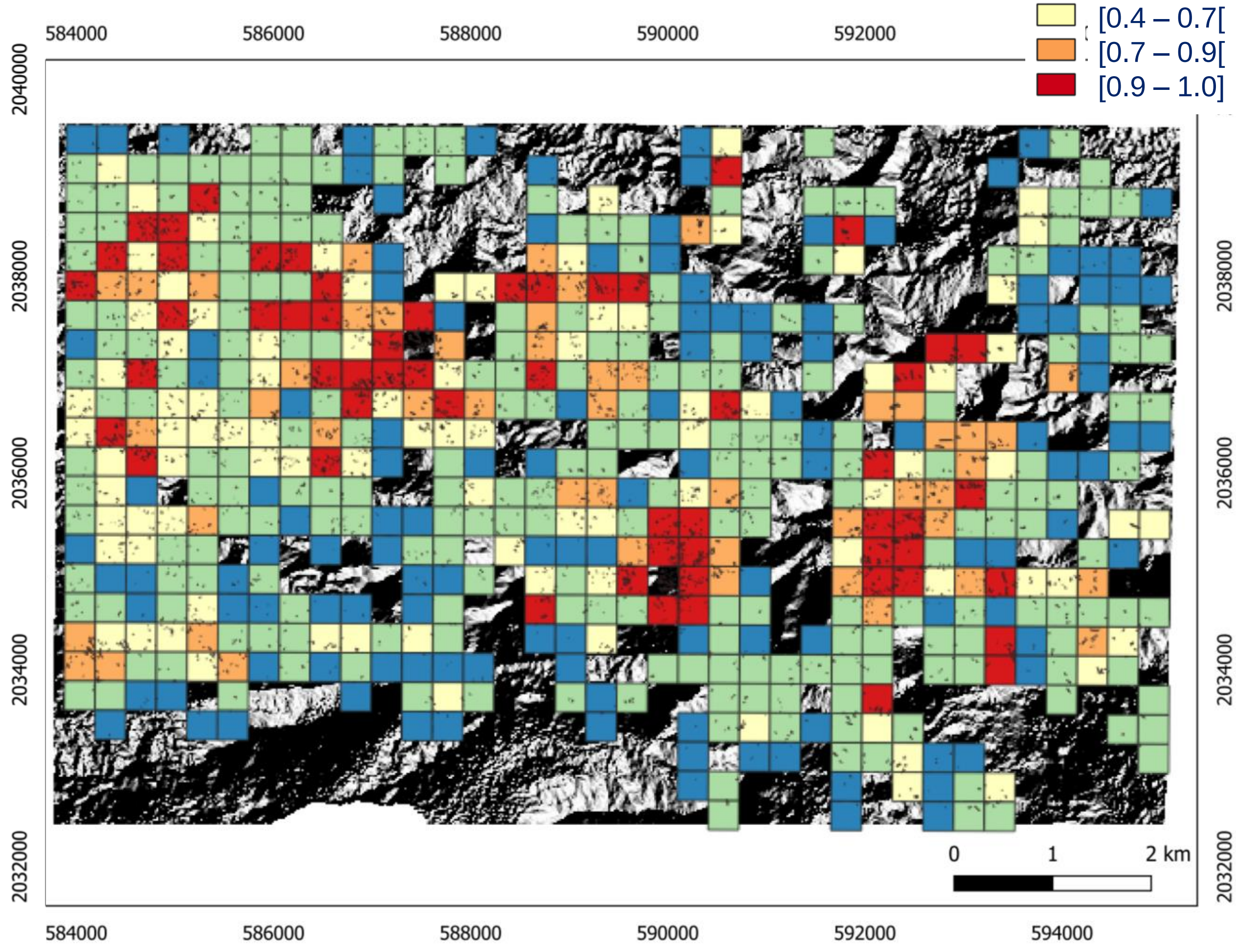
Number of landslides: > 7000
Landslide surface: 4km^2





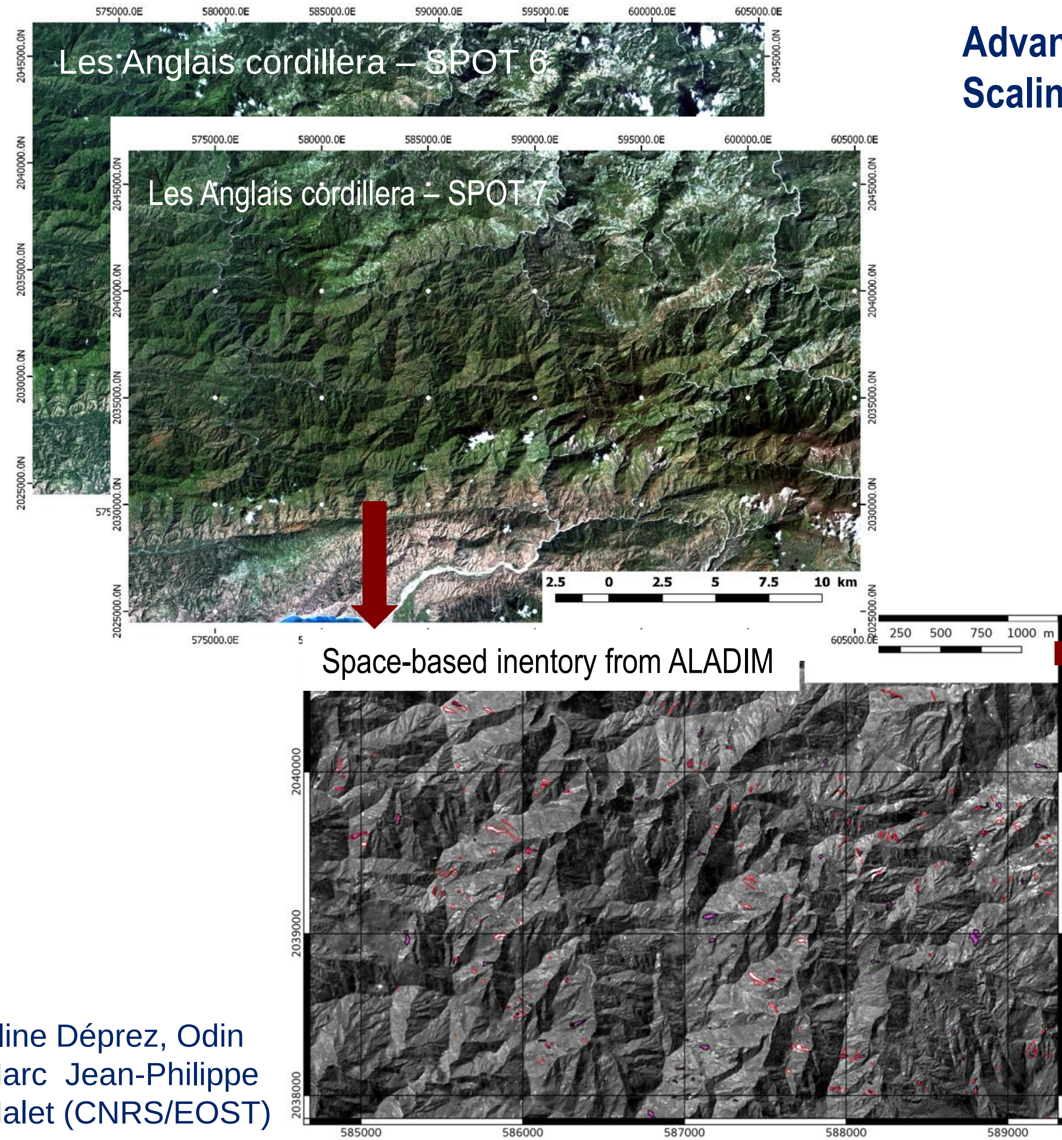
Landslide size (m^2)

Landslide density (over 1 km2 mesh)



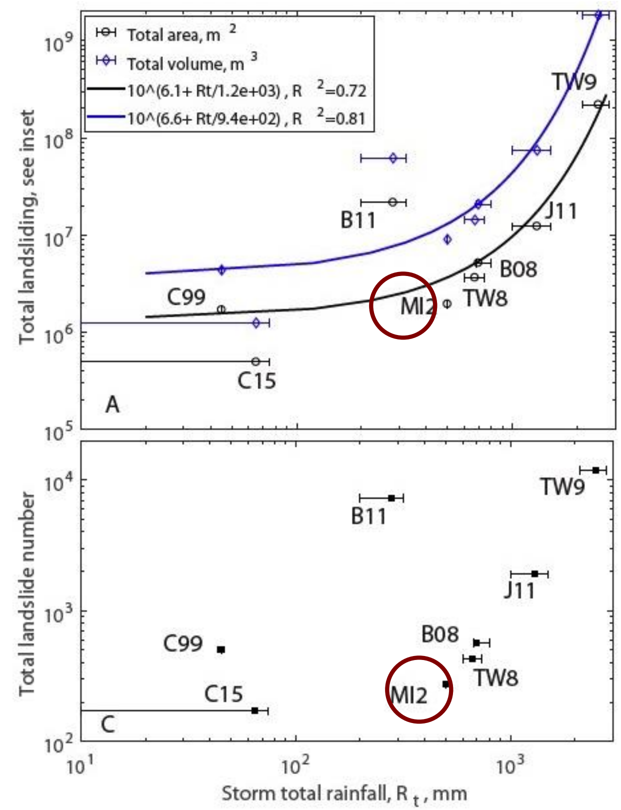
Aline Déprez & Jean-Philippe Malet (CNRS/EOST)

USE OF EO-DERIVED LANDSLIDE INVENTORY: STATISTICS AND TRIGGERS FOR FORECAST



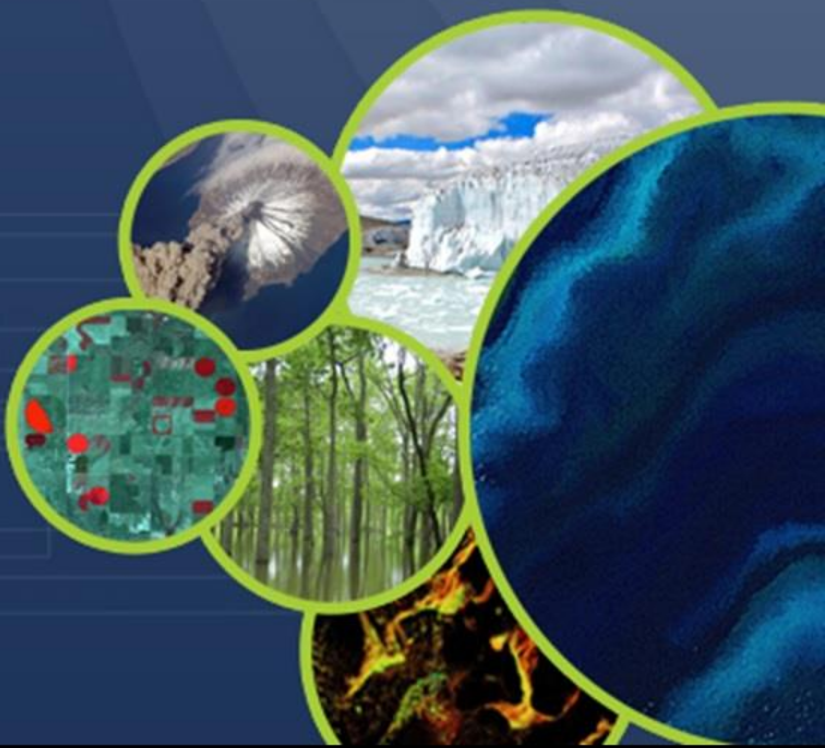
Advanced statistics:
Scaling laws: rainfall pattern vs. landslide size

Landslide properties and rainfall properties (ex. of recent extreme rainfall)



Aline Déprez, Odin Marc Jean-Philippe Malet (CNRS/EOST)

China Study Site



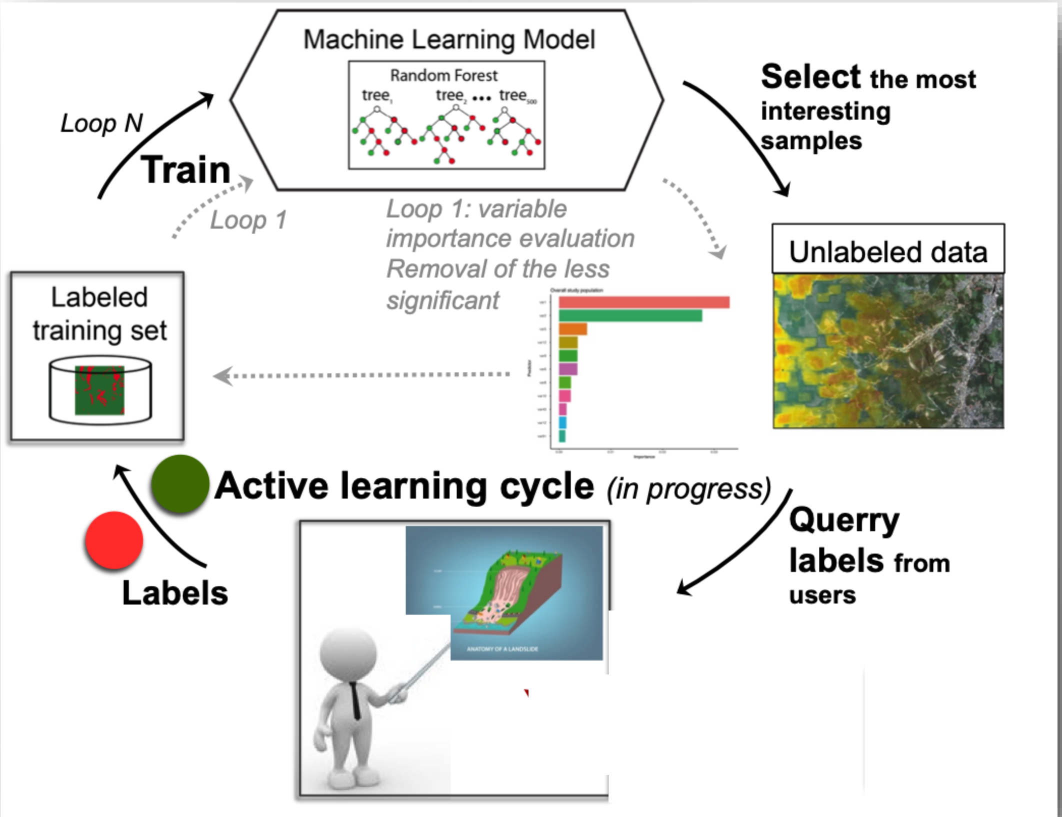
Global Work

Landslide Detection
Event-based inventories

THE NEED FOR EVENT-BASED LANDSLIDE INVENTORIES AT THE GLOBAL SCALE: SEVERAL DETECTION ALGORITHMS AVAILABLE

imCLASS: a generic classifier integrating Machine and Active Learning tools

- Based on ALADIM + New prediction variables + SAR derived index → up to 120 attributes for S2, 70 for Spot
- Higher-level topographic attributes
- Multi-sensor
- Iterative loops – AL cycle
  (to build a robust training sample)
- Per-pixel and segment classification
- Probability maps



ESA/LPS317
Deprez et al. ImClass: A user-tailored Image CLASSification service for land surface mapping

ImCLASS FOR MOZAMBIQUE CYCLONE IDAI – MARCH 2019 SENTINEL 2 DATA

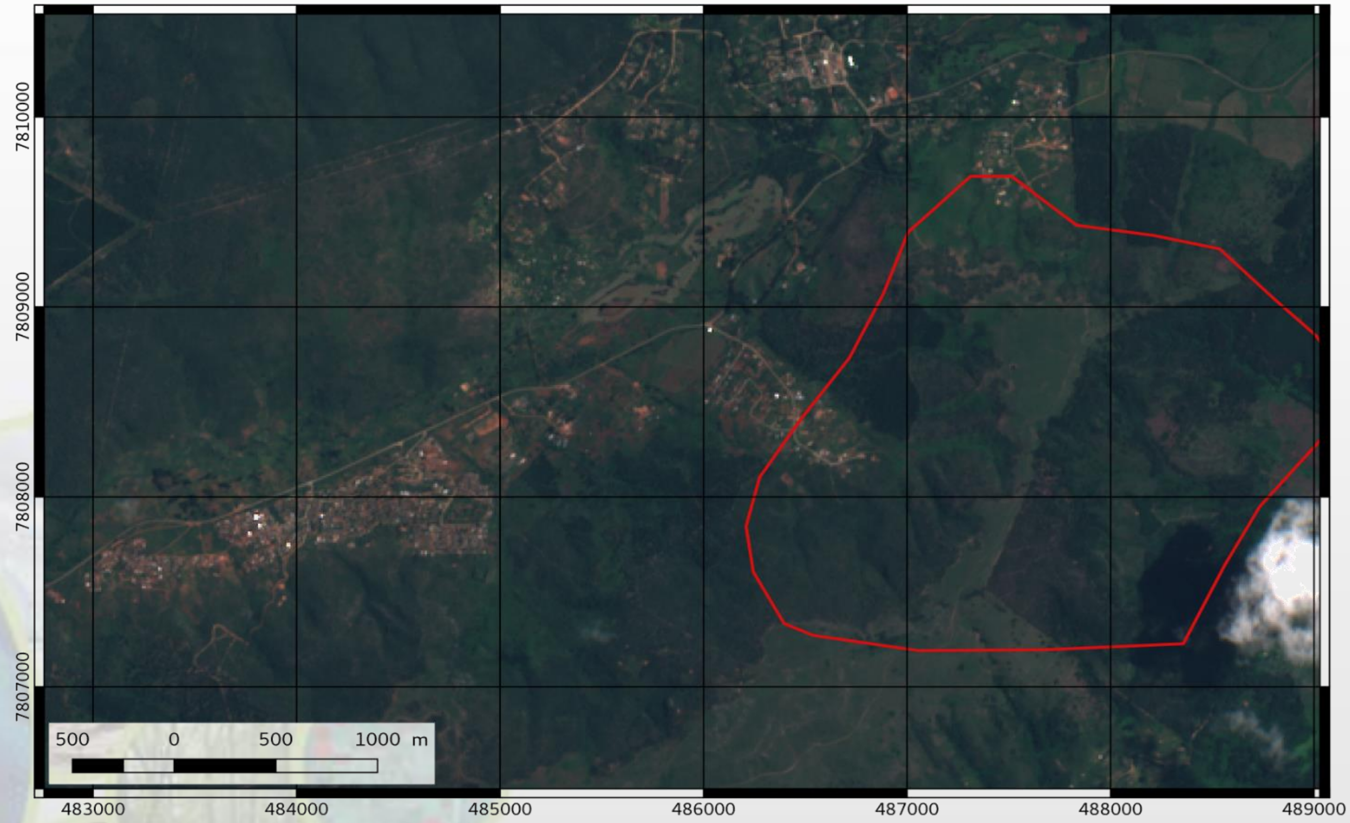
ESA/LPS317

Deprez et al. ImClass: A user-tailored Image CLASSification service for land surface mapping

ImCLASS FOR MOZAMBIQUE CYCLONE IDAI – MARCH 2019 SENTINEL 2 DATA

Sentinel 2 **pre-event**: 23 Feb. 2019
Training area: 100 landslides interpreted for the training sample, eg. ca. 30 min of labour work

Zone 1

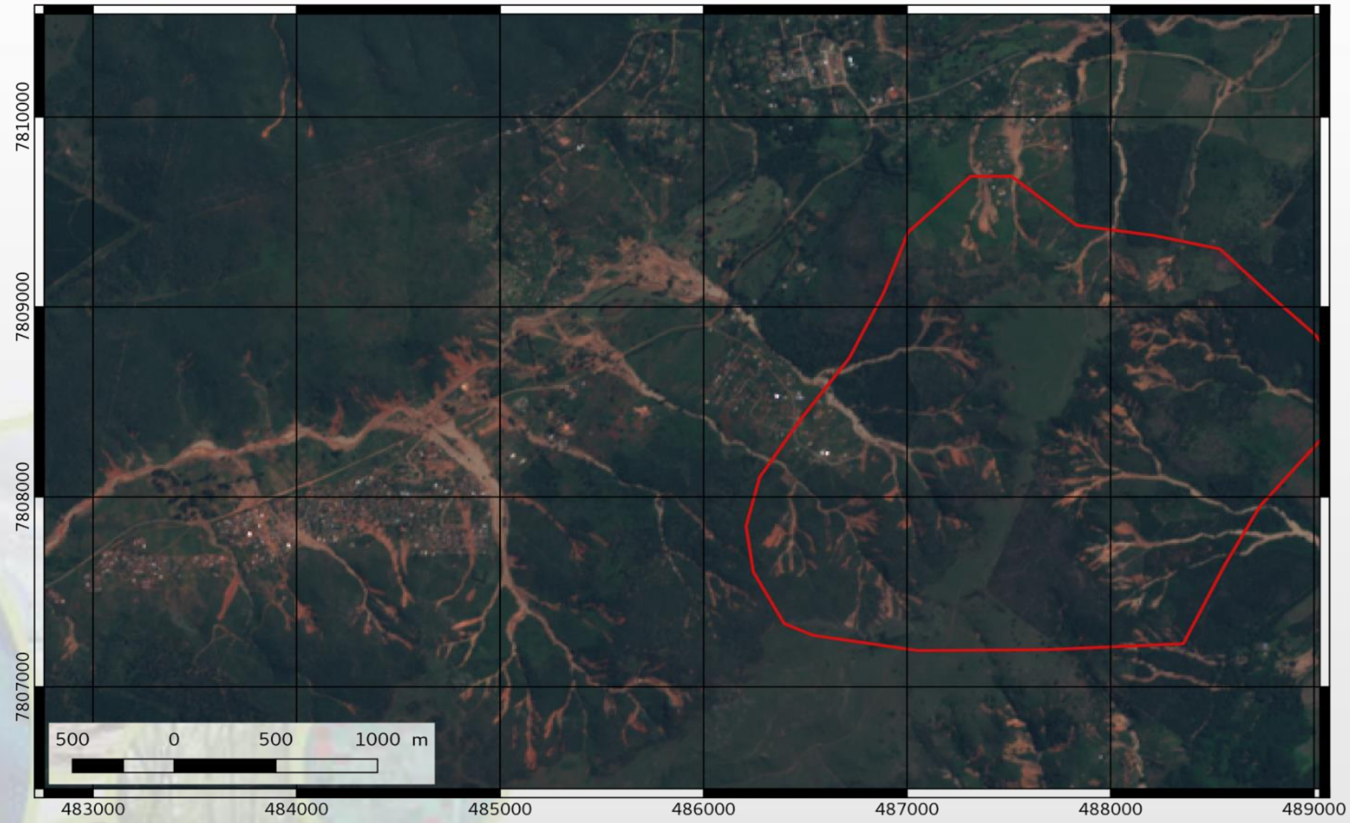


ESA/LPS317
Deprez et al. ImClass: A user-tailored Image CLASSification service for land surface mapping

ImCLASS FOR MOZAMBIQUE CYCLONE IDAI – MARCH 2019 SENTINEL 2 DATA

Sentinel 2 **post-event**: 25 March 2019
Training area: 100 landslides interpreted for the training sample, eg. ca. 30 min of labour work

Zone 1

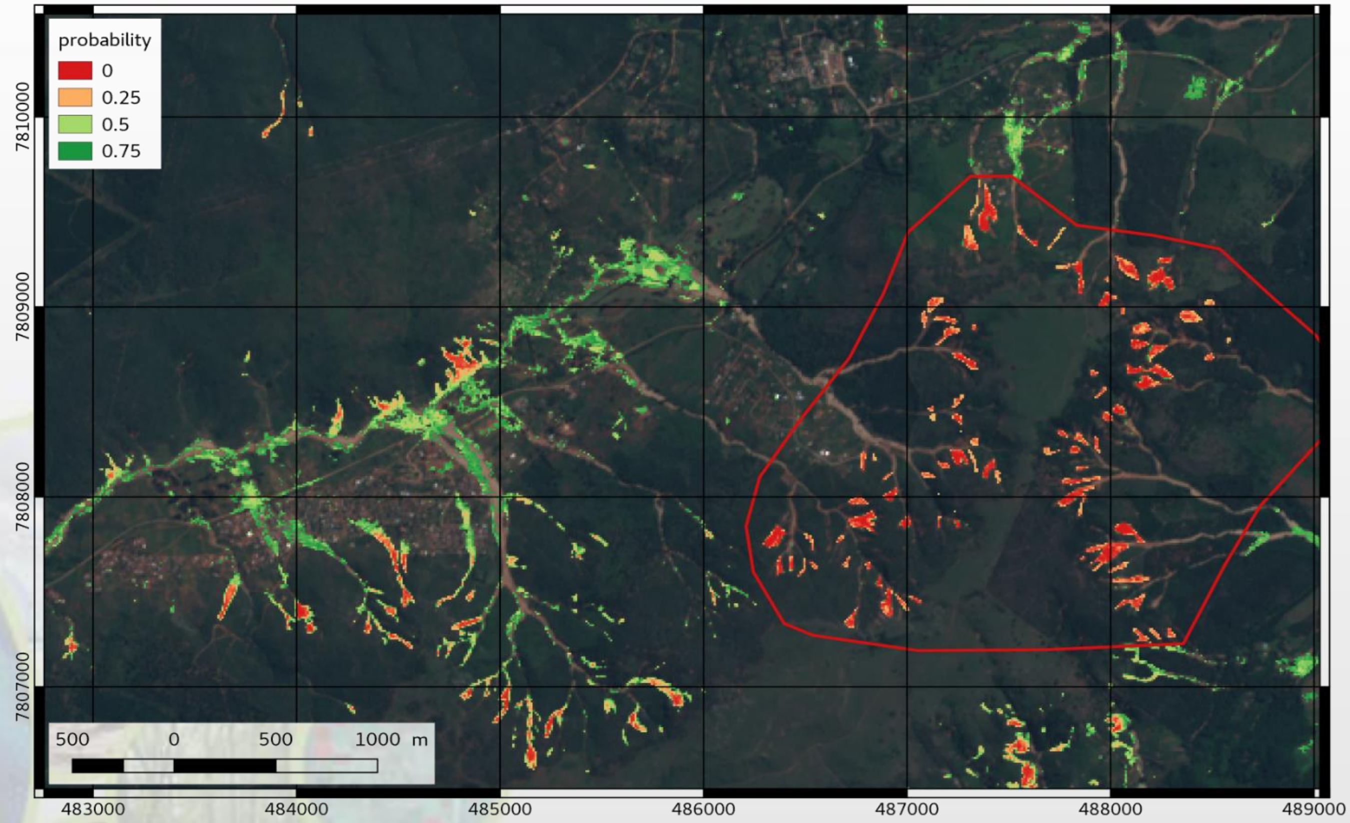


ESA/LPS317
Deprez et al. ImClass: A user-tailored Image CLASSification service for land surface mapping

ImCLASS FOR MOZAMBIQUE CYCLONE IDAI – MARCH 2019 SENTINEL 2 DATA

imCLASS results: landslides + probability of classification
Computation: 1 hour for 1 S2 tile -> for this sub-region / experiment, 550 landslides detected ….
.

Zone 1

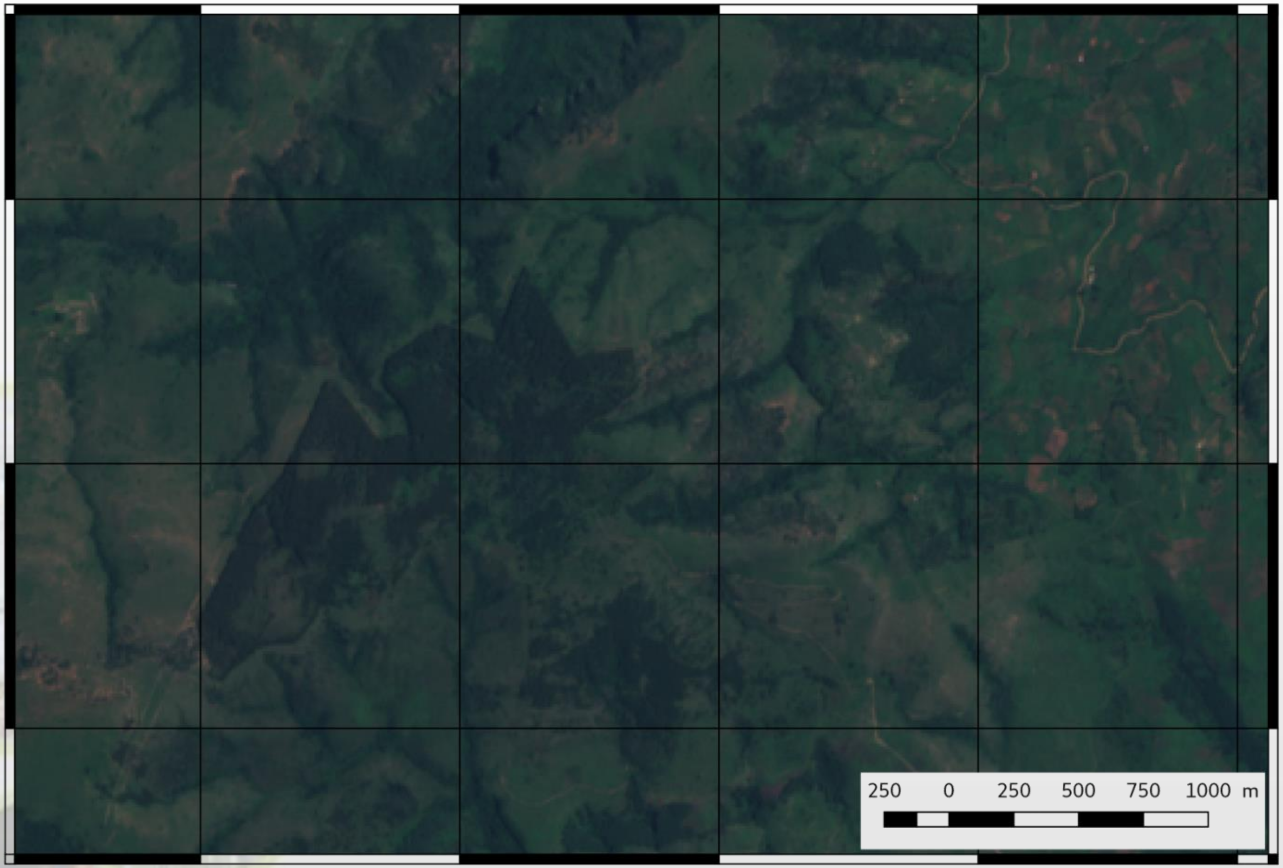


ESA/LPS317
Deprez et al. ImClass: A user-tailored Image CLASSification service for land surface mapping

ImCLASS FOR MOZAMBIQUE CYCLONE IDAI – MARCH 2019 SENTINEL 2 DATA

Sentinel 2 **pre-event**: 23 Feb. 2019
Zone with no reference inventory

Zone 2



ImCLASS FOR MOZAMBIQUE CYCLONE IDAI – MARCH 2019 SENTINEL 2 DATA

Sentinel 2 **post-event**: 25 March 2019
Zone with no reference inventory

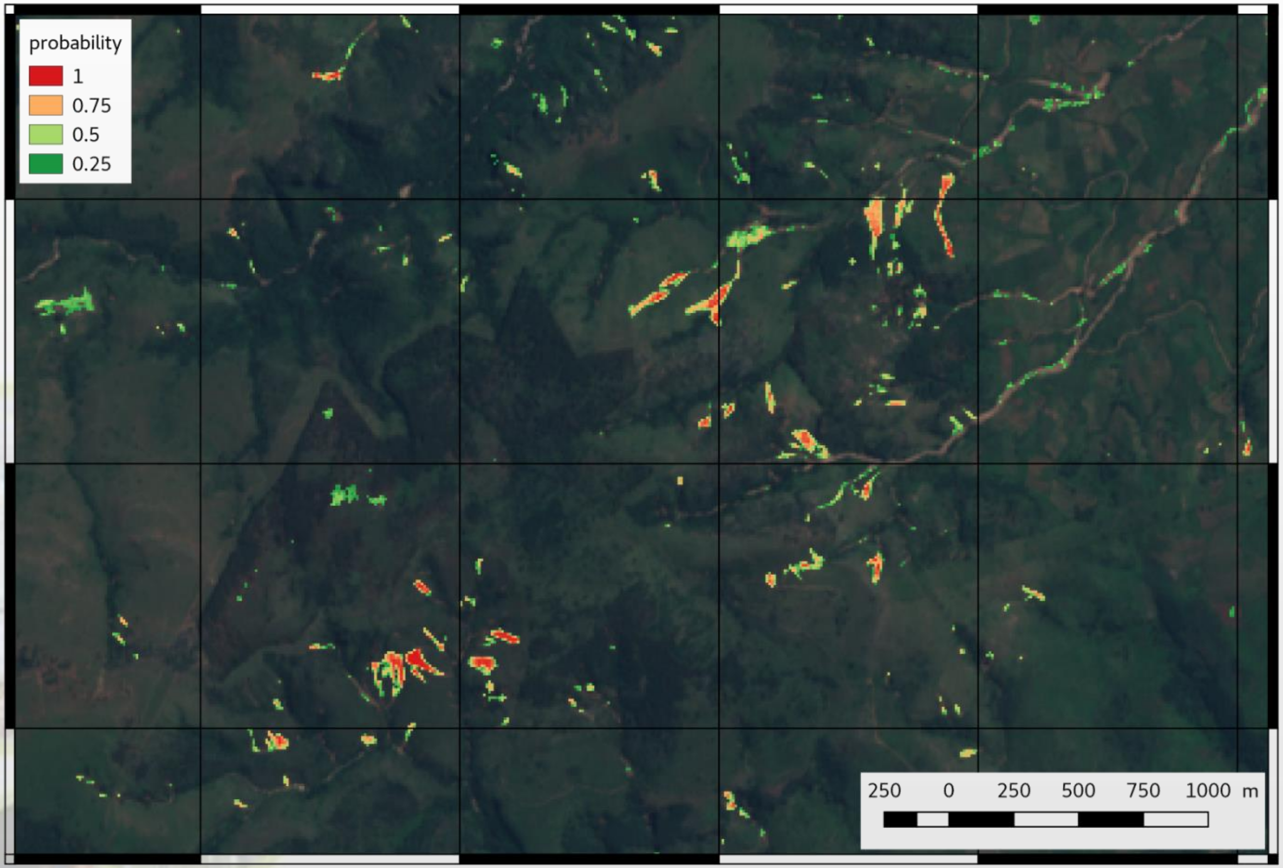
Zone 2

ESA/LPS317
Deprez et al. ImClass: A user-tailored Image CLASSification service for land surface mapping

ImCLASS FOR MOZAMBIQUE CYCLONE IDAI – MARCH 2019 SENTINEL 2 DATA

imCLASS results: landslides + probability of classification
Computation: 1 hour for 1 S2 tile -> for this sub-region / experiment, 280 landslides detected ….

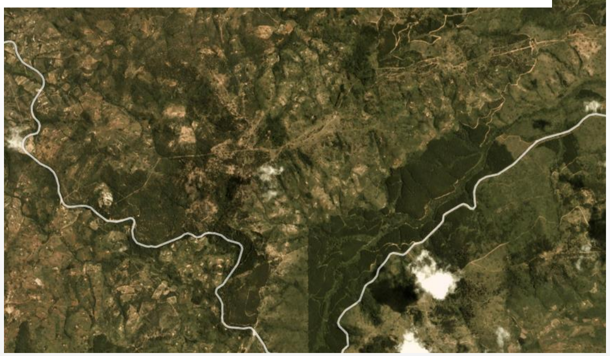
Zone 2



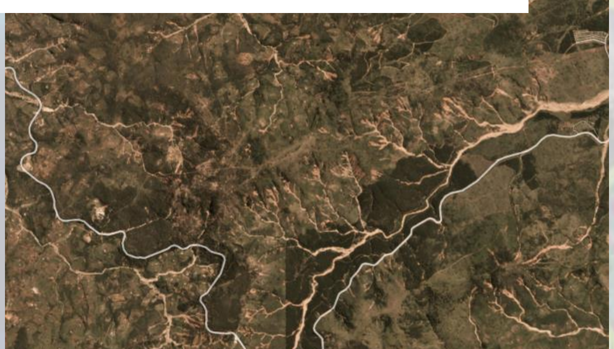
ESA/LPS317
Deprez et al. ImClass: A user-tailored Image CLASSification service for land surface mapping

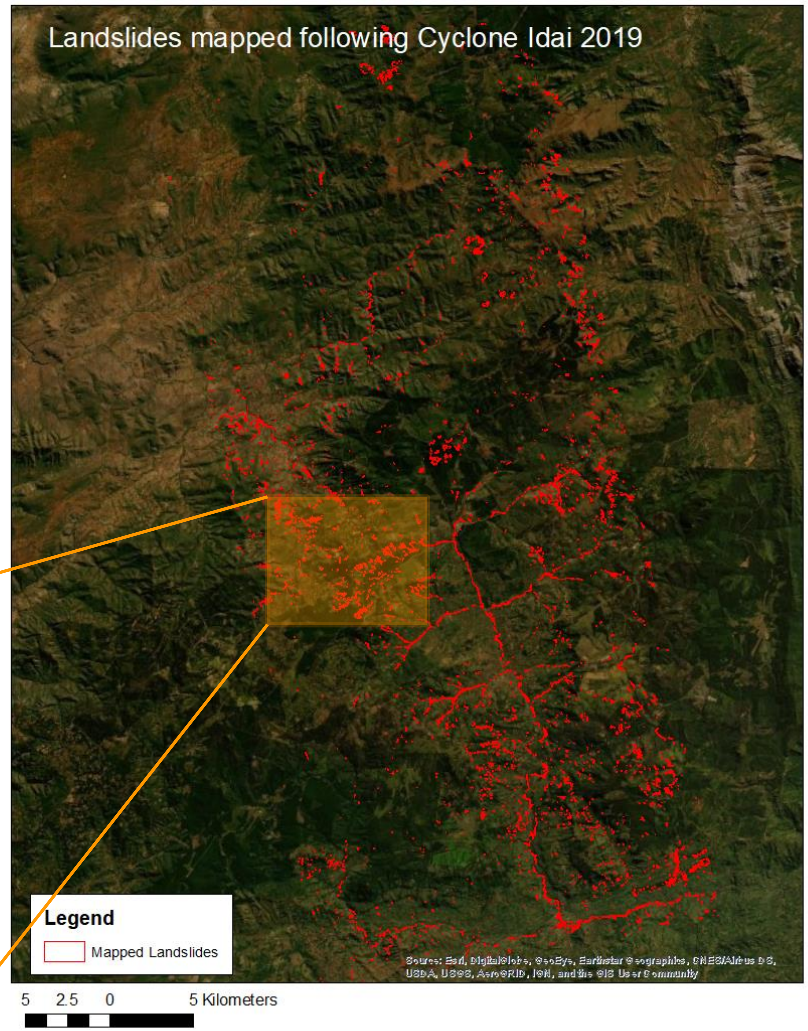
Cyclone Idai, Mozambique (March, 2019) on Very-High Resolution images

Before: Planet Dove RGB and NIR



After: Planet Dove RGB and NIR





The Landslides team used a new landslide detection algorithm to identify landslides triggered by Cyclone Idai that impacted Mozambique in March 2019.

Over 4800 landslides were mapped

Credit: Amatya, Emberson & Kirschbaum

ImCLASS FOR JAPAN
JULY 2019 HEAVY RAINS
KYUSHU PROVINCE

NATIONAL

More than 1.09 million residents in Kyushu ordered to evacuate as torrential rains continue

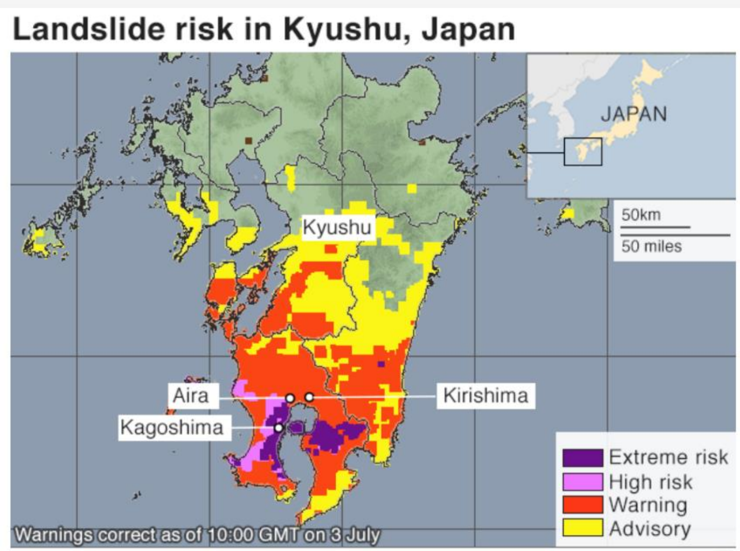
KYODO

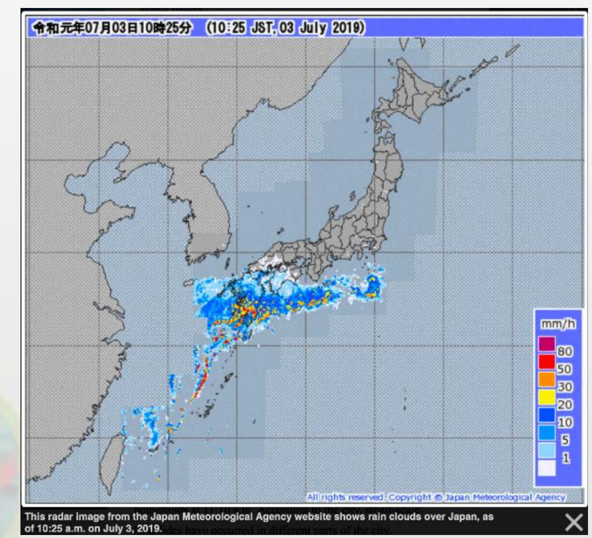
More than 1.09 million residents across two prefectures in Kyushu, including the entire populations of three cities in Kagoshima Prefecture, were ordered to evacuate as of 6 p.m. Wednesday, as continuing torrential rain raised the risk of floods and mudslides.

JUL 3, 2019

ARTICLE HISTORY

PRINT SHARE



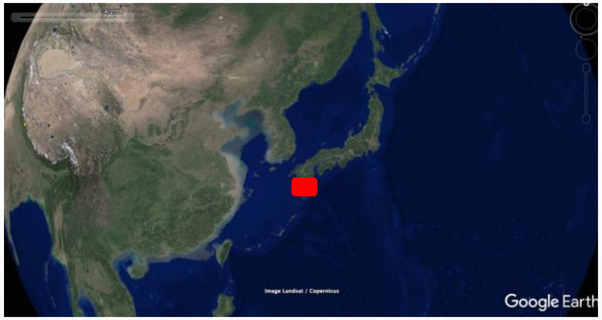


Rain forecast, Kyushu, Japan

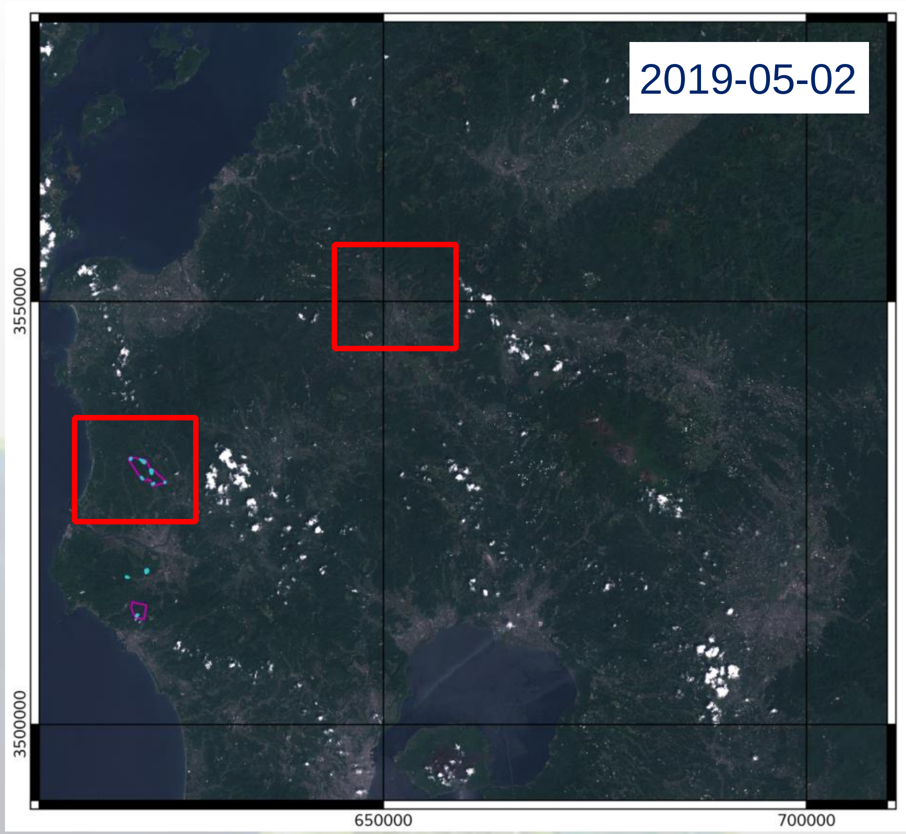
The area where a landslide occurred, hitting a residence, is seen in the town of Honjo, Kagoshima Prefecture, on the morning of July 1, 2019. (Mainichi/Takaharu Nishi)

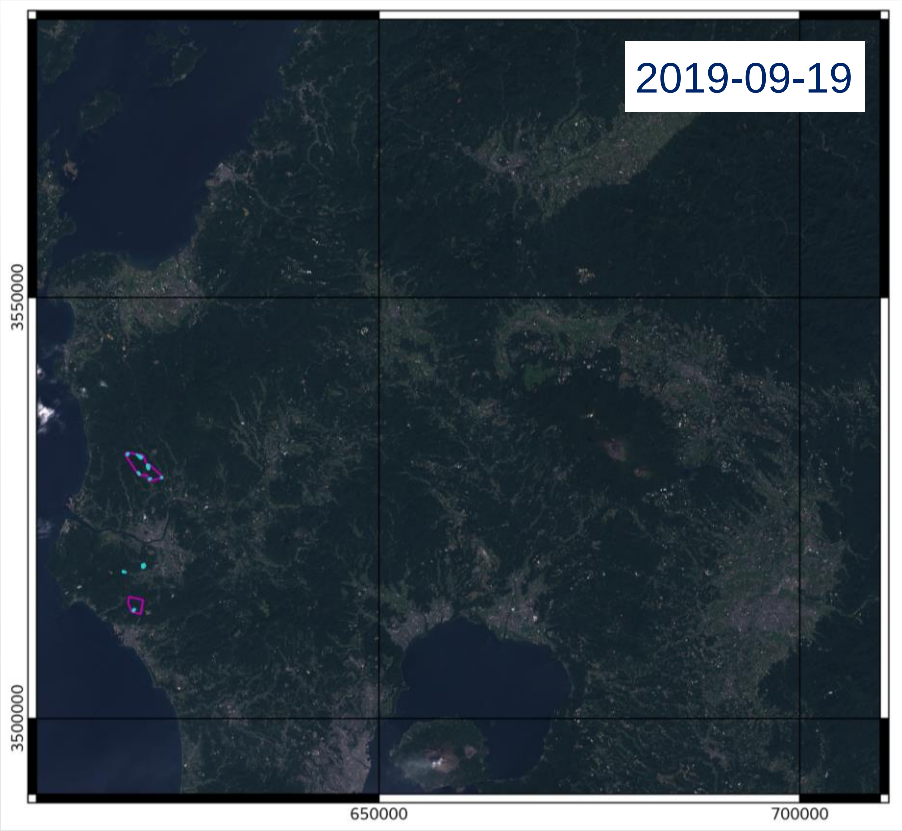
Déprez et Malet, 2019

ImCLASS FOR JAPAN
JULY 2019 HEAVY RAINS – KYUSHU
SENTINEL 2 DATA



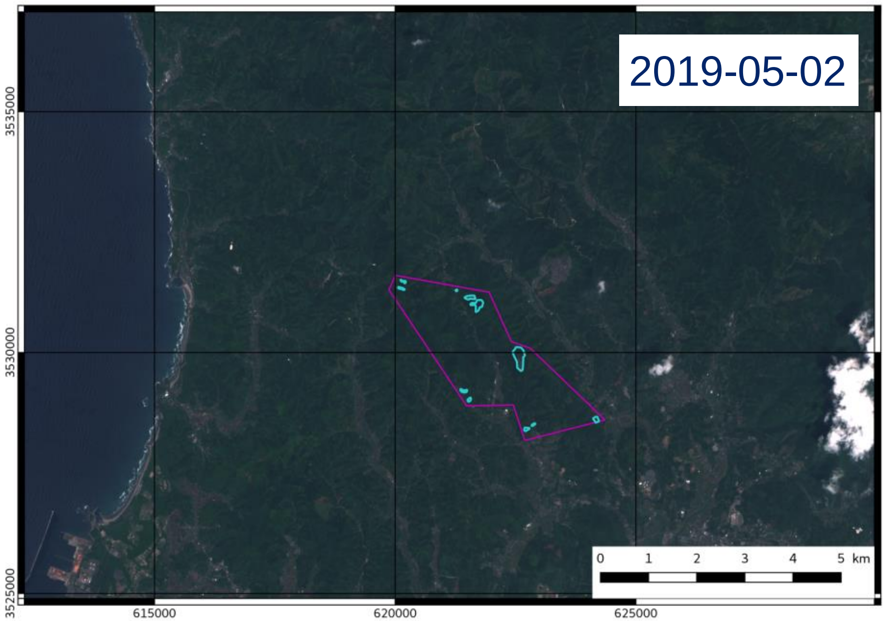
Pre- and post- the heavy rains of 2 July 2019

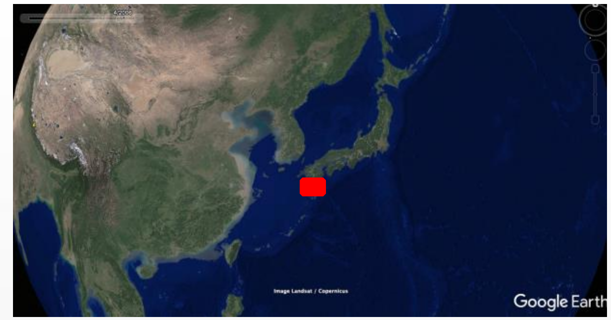




Déprez et Malet, 2019

ImCLASS FOR JAPAN
JULY 2019 HEAVY RAINS – KYUSHU
SENTINEL 2 DATA

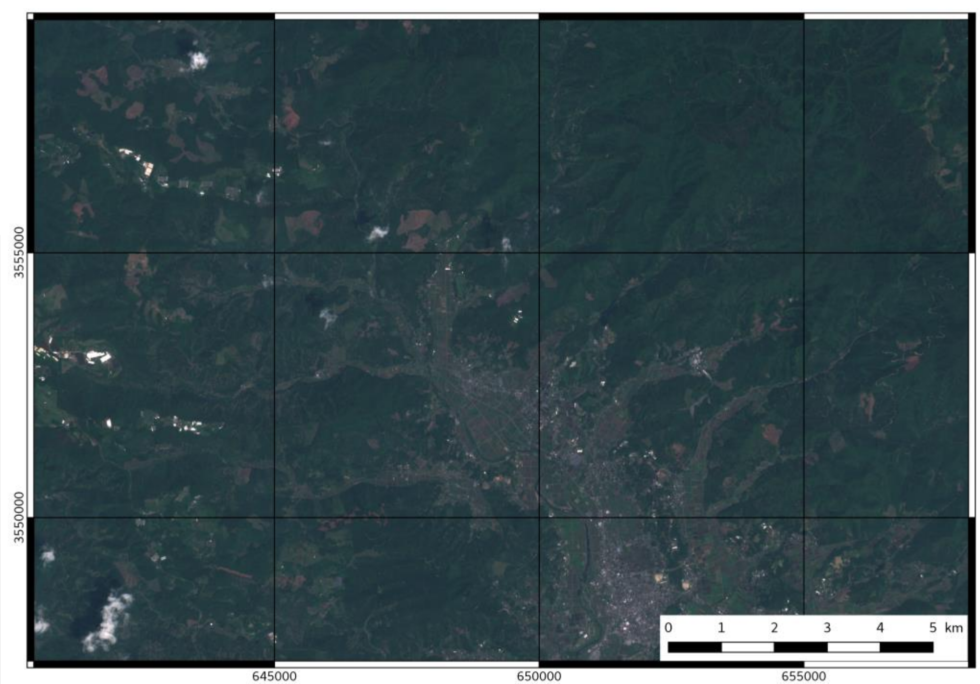




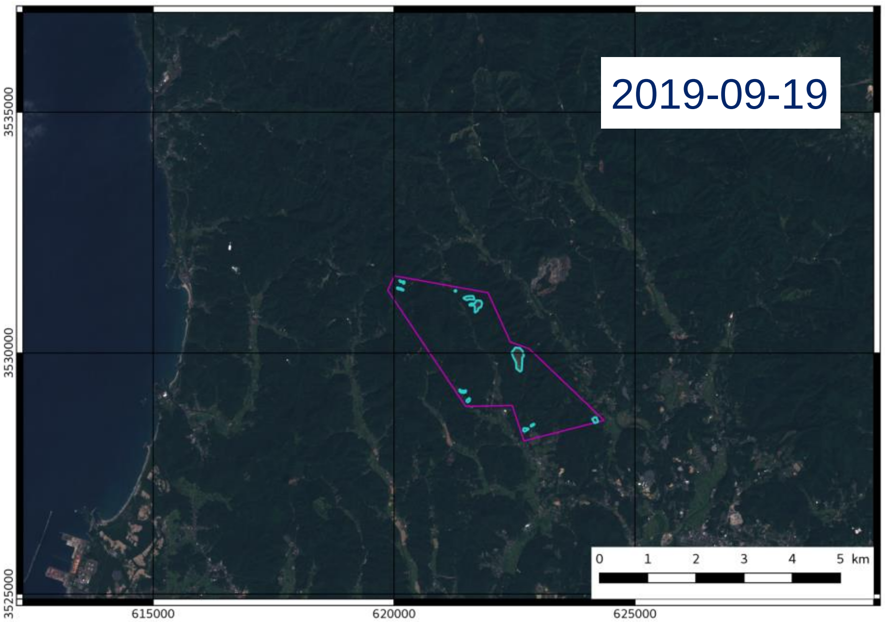
Pre-event image: 2019/05/02

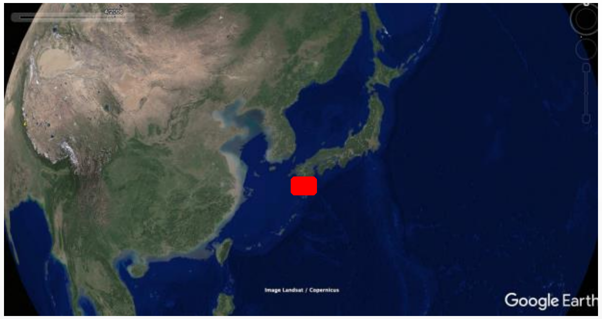
Red: Training area
Blue : Training sample – 10 min digit

Zoom



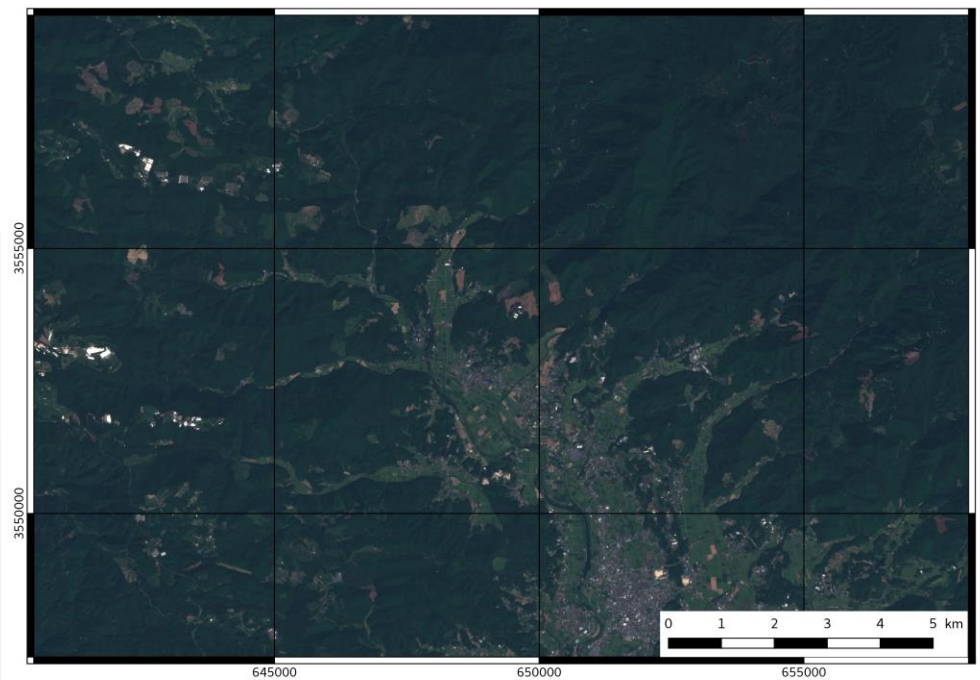
ImCLASS FOR JAPAN
JULY 2019 HEAVY RAINS – KYUSHU
SENTINEL 2 DATA





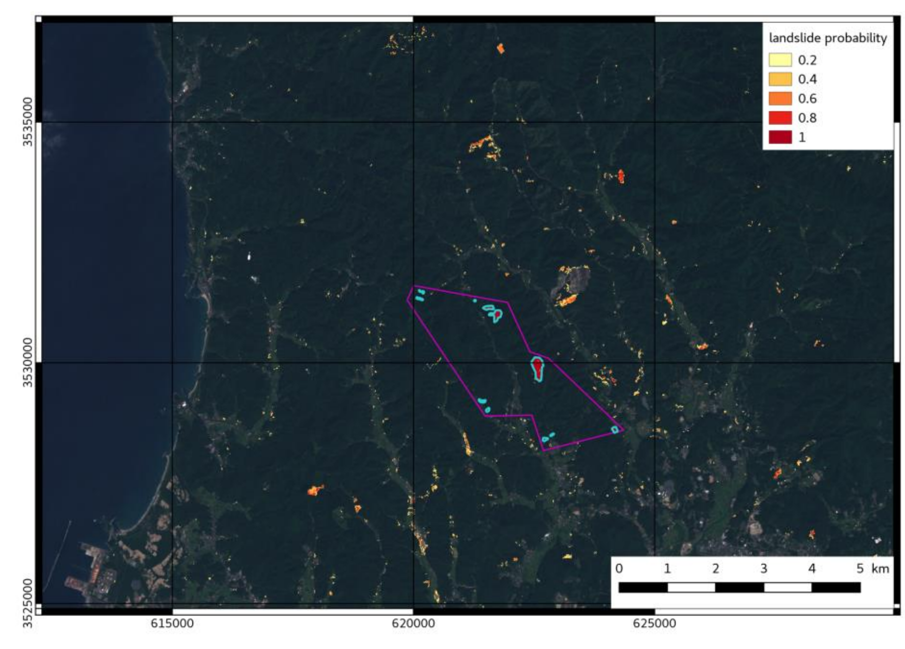
Post-event image: 2019/09/19

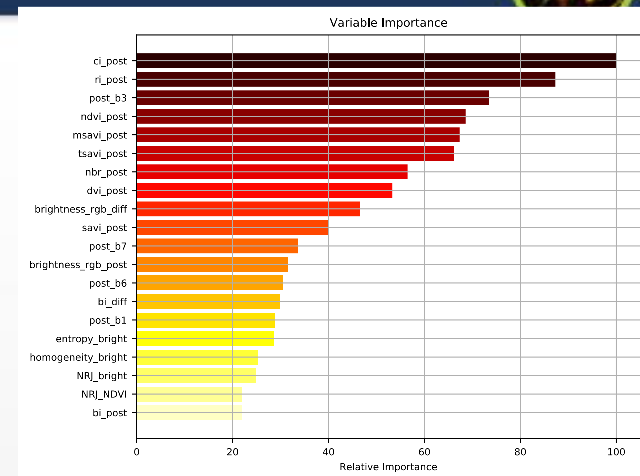
Red: Training area
Blue : Training sample – 10 min digit

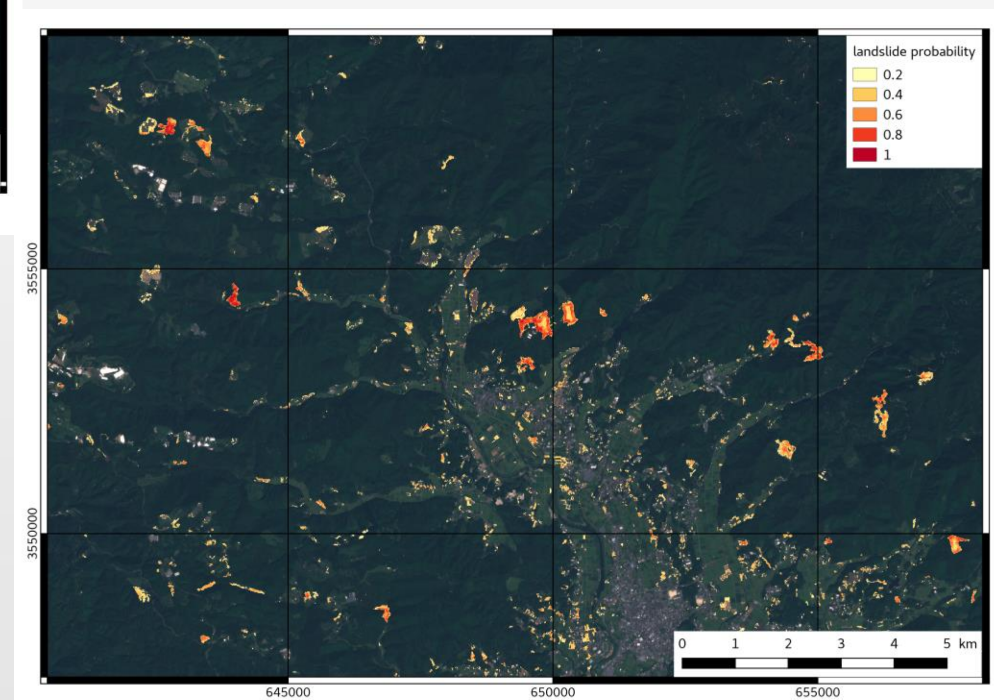


Déprez et Malet, 2019

ImCLASS FOR JAPAN
JULY 2019 HEAVY RAINS – KYUSHU
SENTINEL 2 DATA



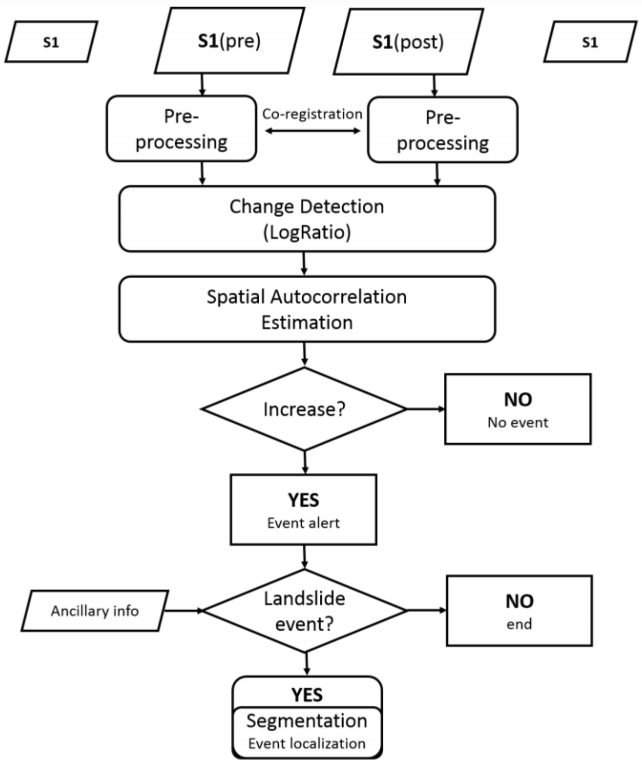


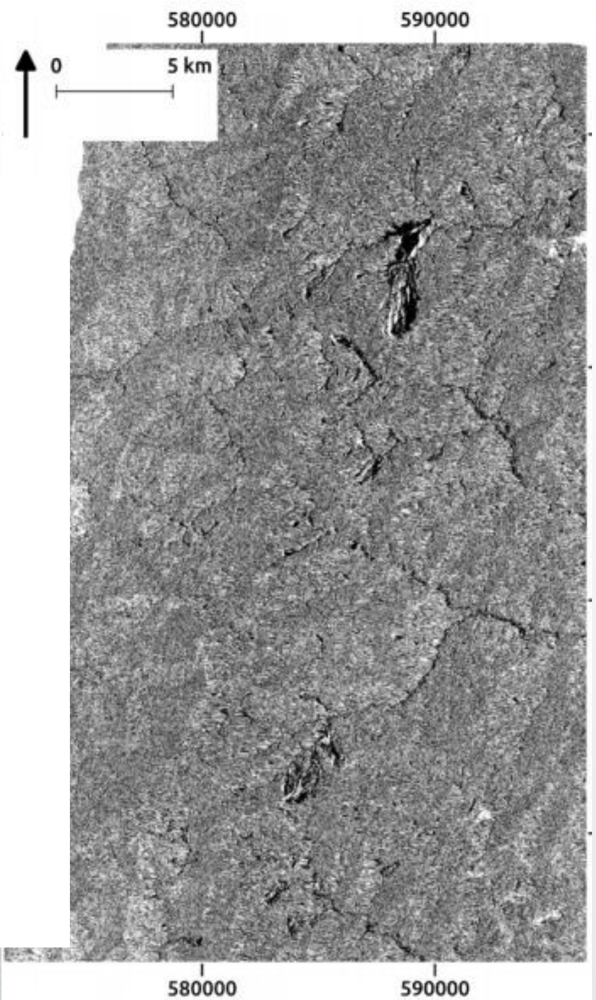


Déprez et Malet, 2019

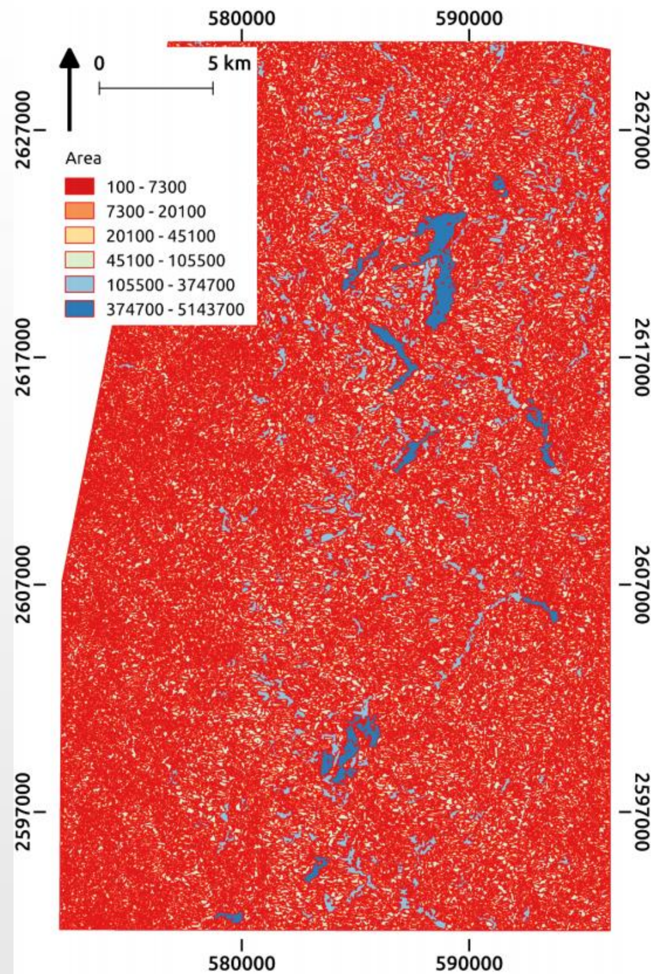
Event based landslide detection using Spatial Autocorrelation Changes in Multitemporal SAR Images (Sentinel-1)

Study Area:
Chin Division, Myanmar





the LogRatio layer obtained using the last pre and the first post-event SAR images



Segmentation of the LogRatio layer

Mondini 2017

Sentinel-1 SAR Amplitude Imagery for Rapid Landslide Detection

Landslide interpretation capability was tested for 32 events around the world using change detection (LogRatio) of Pre and post Sentinel1-imagery.

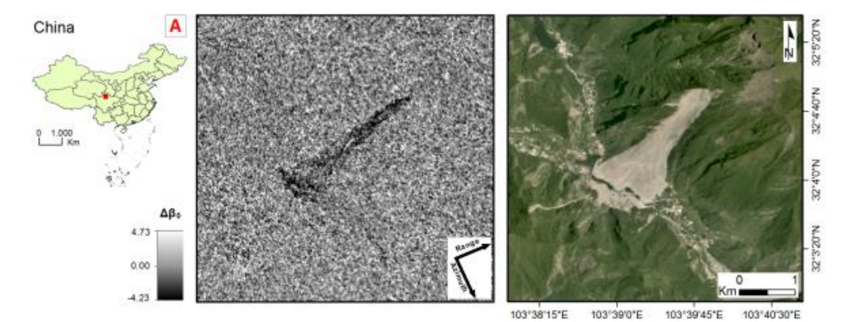
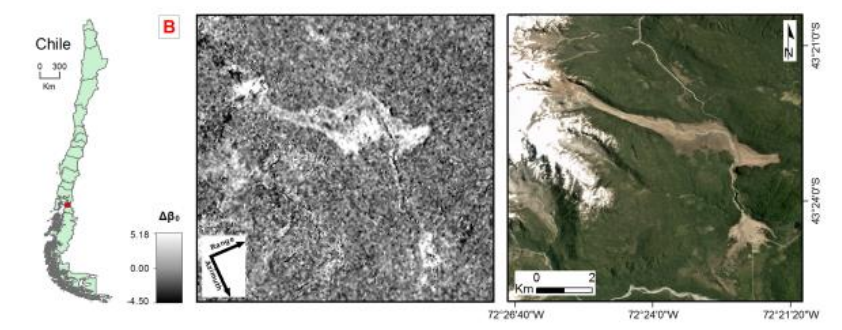
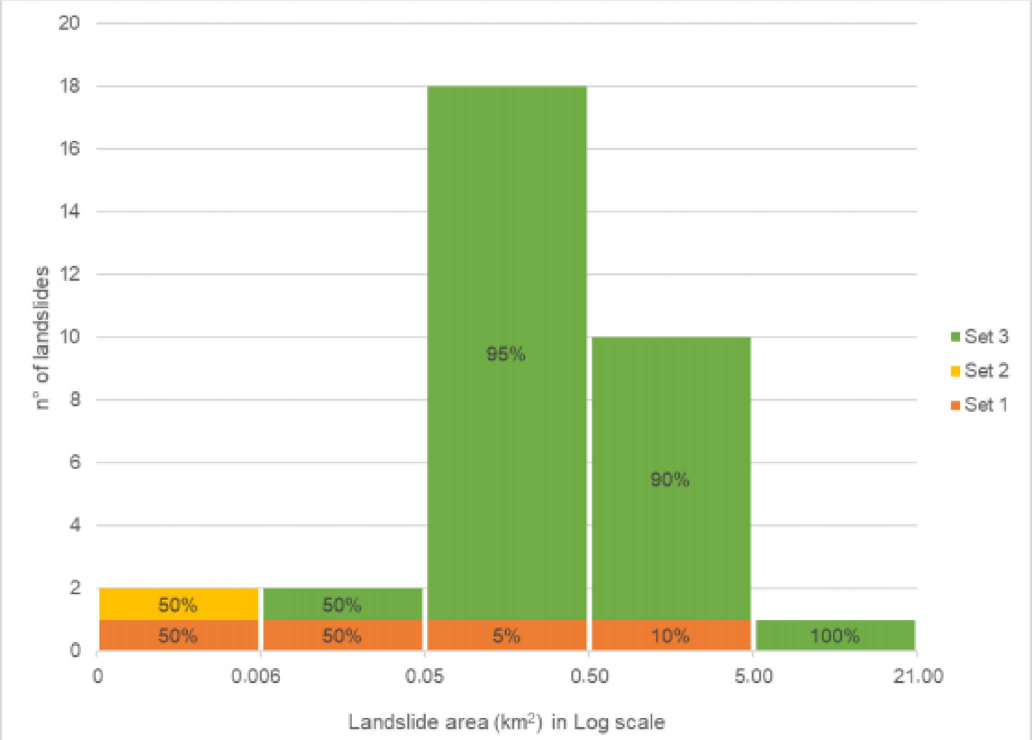


Figure 1. The Maoxian (China) landslide (case A in Table 1). On the **left**: landslide location, in the middle: the measure of SAR amplitude changes, on the **right**: the landslide in the optical image (from https://www.planet.com).



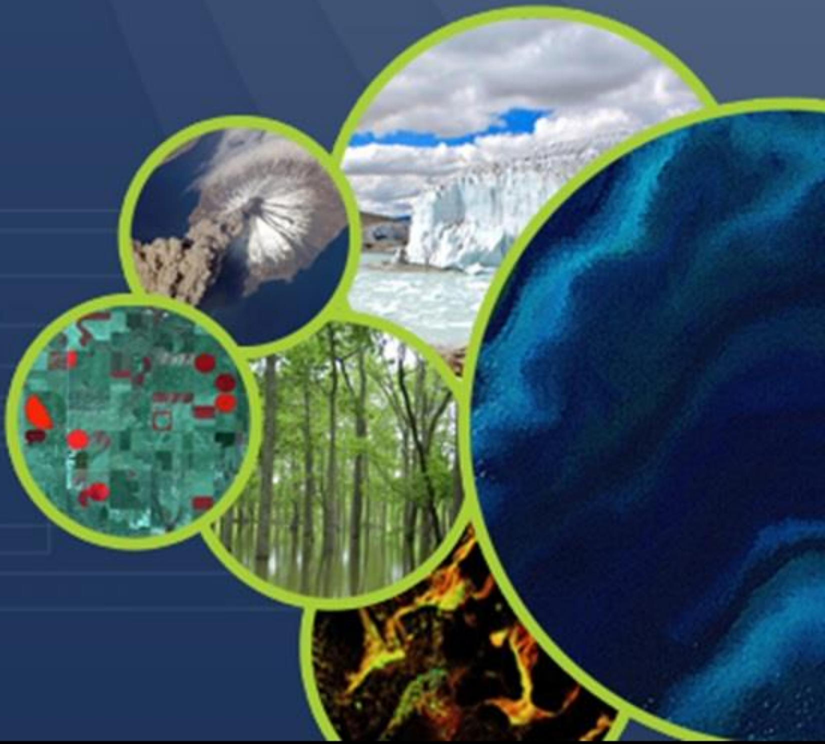


set 1 corresponds to landslides that we were not able to recognize, set 2 to landslides recognized only knowing a priori the location, and set 3 the successful cases. Results show that in about eighty-four percent of the cases, changes caused by landslides on SAR amplitudes are unambiguous, whereas only in about thirteen percent of the cases there is no evidence

Mondini 2019

Global work

Landslide Thresholds



Can we constrain global landslide-rainfall scaling with satellite measurements?

Spatial patterns of storm-induced landslides and their relation to rainfall anomaly maps at short and long timescales

Odin Marc[1*], Marielle Gosset[2], Hitoshi Saito[3], Taro Uchida[4] and Jean-Philippe Malet[1]

[1] École et Observatoire des Sciences de la Terre □ Institut de Physique du Globe de Strasbourg, Centre National de la Recherche Scientifique UMR 7516, University of Strasbourg, 67084 Strasbourg Cedex, France

[2] IRD / Géosciences Environnement Toulouse, 31400 Toulouse, France

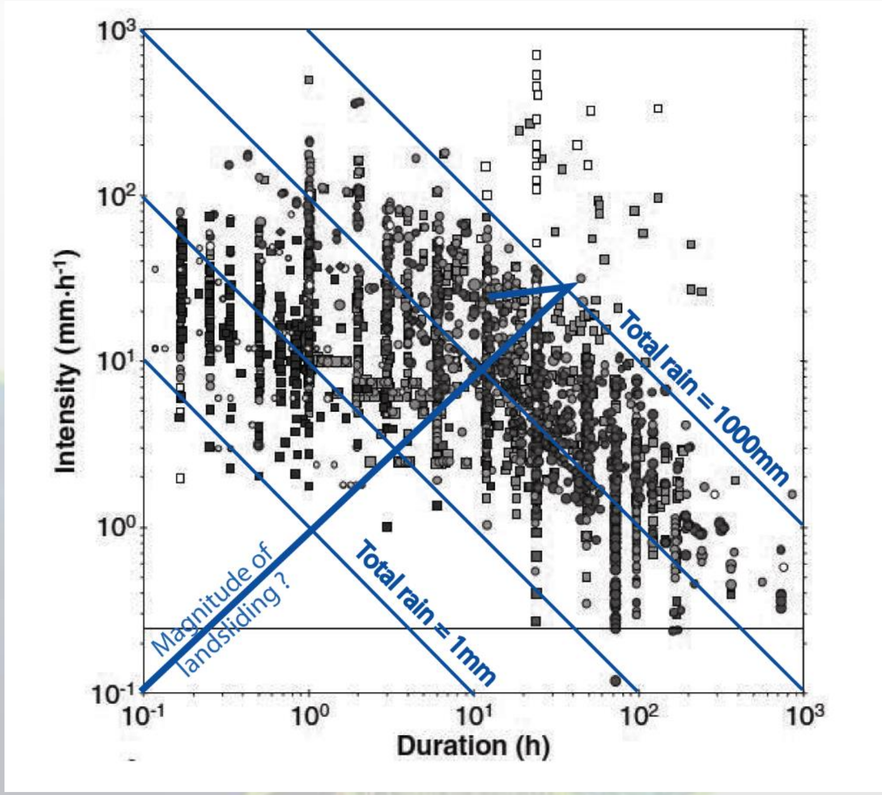
[3] College of Economics, Kanto Gakuin University, Kanagawa, Japan

[4] National Institute for Land and Infrastructure Management, Tsukuba, Japan.

Brazil, January 2011 (GeoEye image)

Empirical approach: Rainfall threshold

Conventional approach: relate the occurence of a given landslide to nearby meteorological information. Almost no information on landslides usefull for RISK



Guzzetti, et al., 2008

→ How rainfall drives landslide beyond the threshold ?

i) Inter-storm variability ?

ii) Intra storm variability ?

→ Can we rely on satellital rainfall estimates for landslide studies?

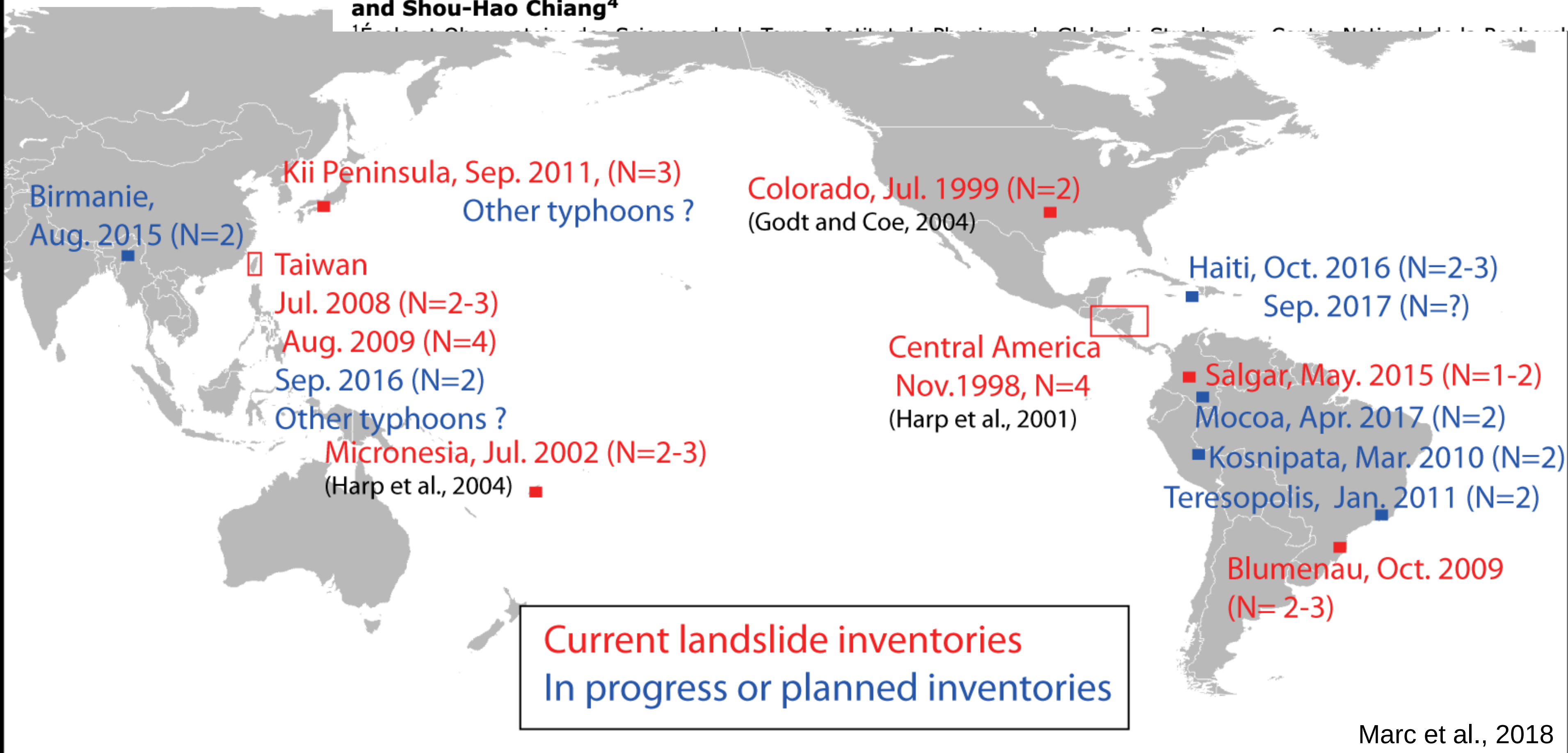
Compilation of comprehensive event-based inventories

Earth Surf. Dynam., 6, 903–922, 2018
https://doi.org/10.5194/esurf-6-903-2018

Research article

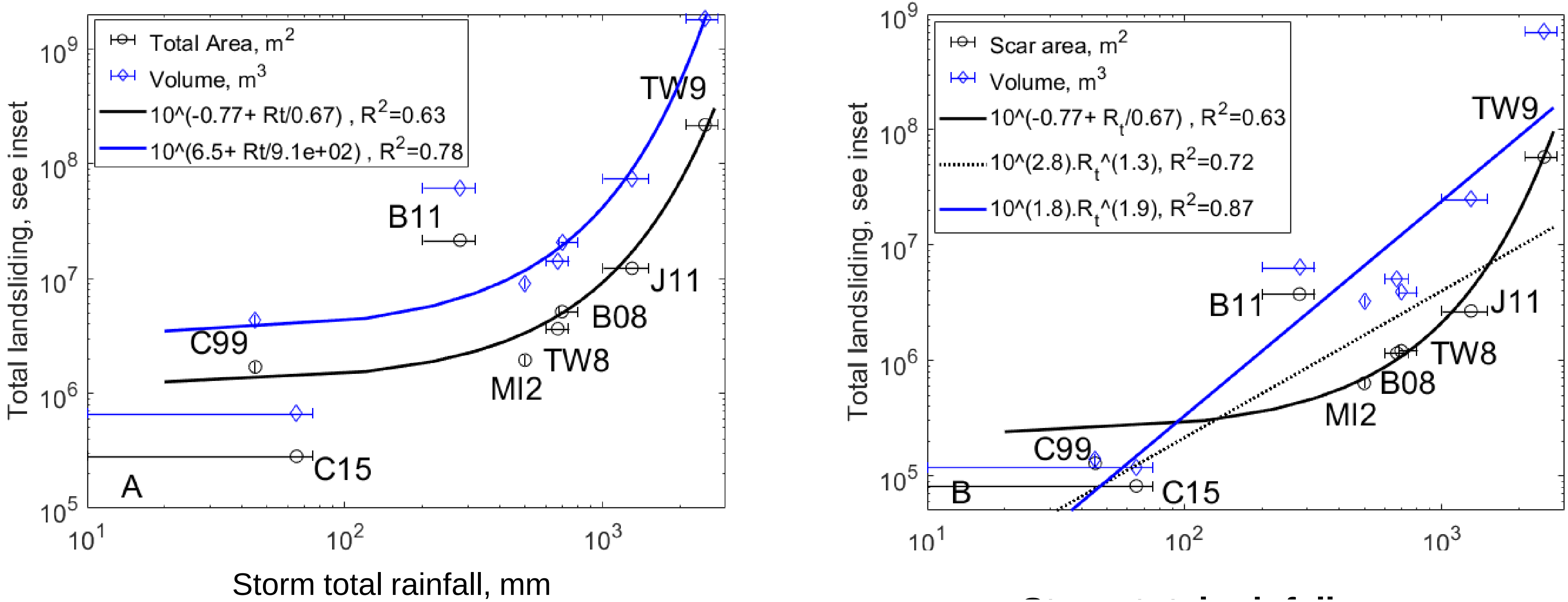
Initial insights from a global database of rainfall-induced landslide inventories: the weak influence of slope and strong influence of total storm rainfall

Odin Marc[1], André Stumpf[1], Jean-Philippe Malet[1], Marielle Gosset[2], Taro Uchida[3], and Shou-Hao Chiang[4]



Scaling laws: total landsliding (surface)

Whole landslide **Scar estimate**



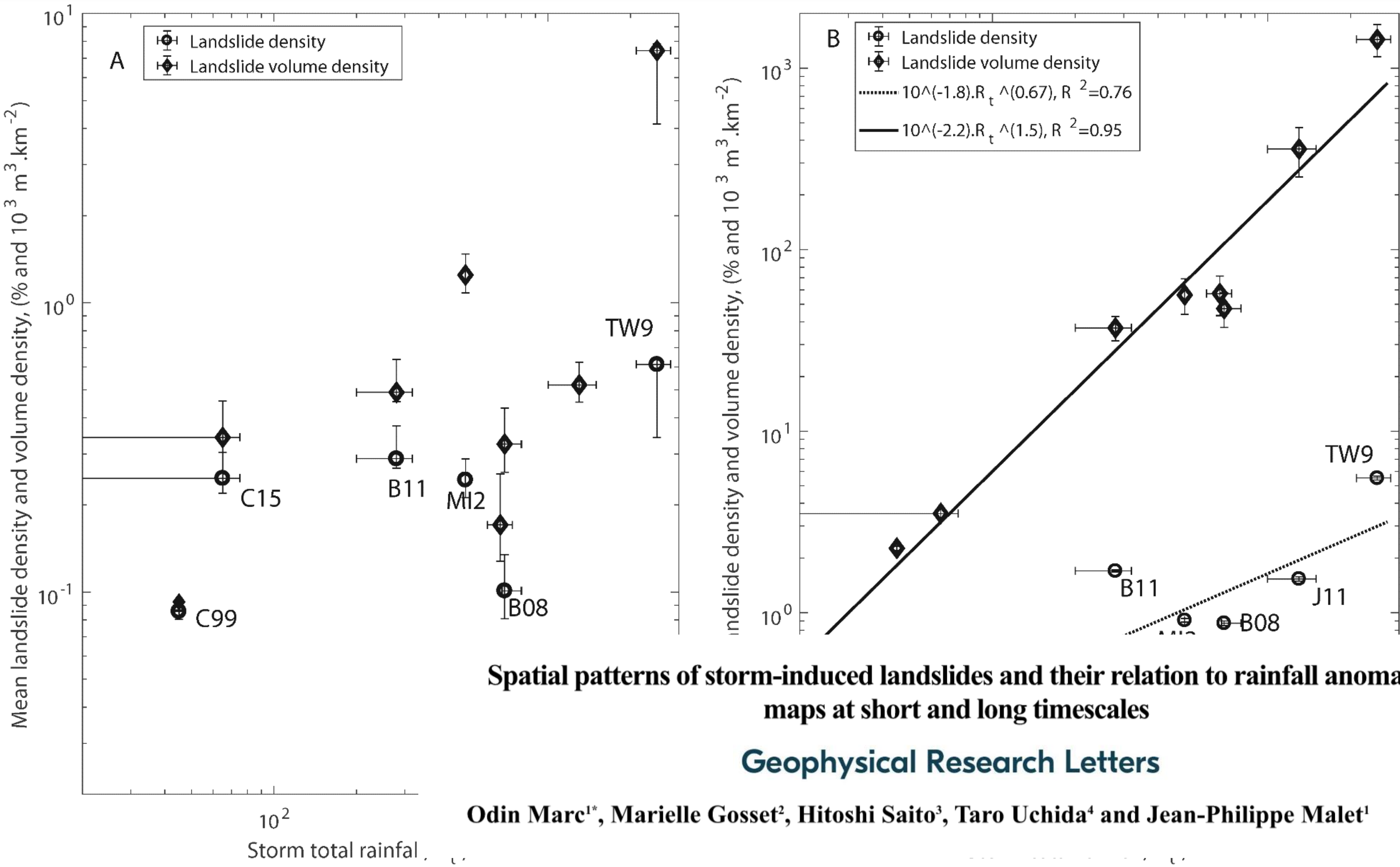
Spatial patterns of storm-induced landslides and their relation to rainfall anomaly maps at short and long timescales

Geophysical Research Letters

Odin Marc[1*], Marielle Gosset[2], Hitoshi Saito[3], Taro Uchida[4] and Jean-Philippe Malet[1]

Compilation of comprehensive event-based inventories

Scaling laws: total landsliding (mean/max density)



Spatial patterns of storm-induced landslides and their relation to rainfall anomaly maps at short and long timescales

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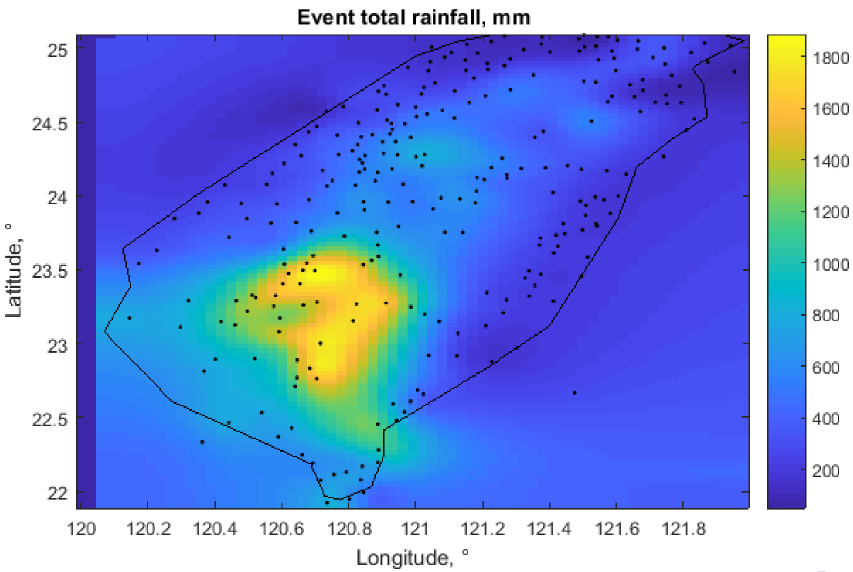
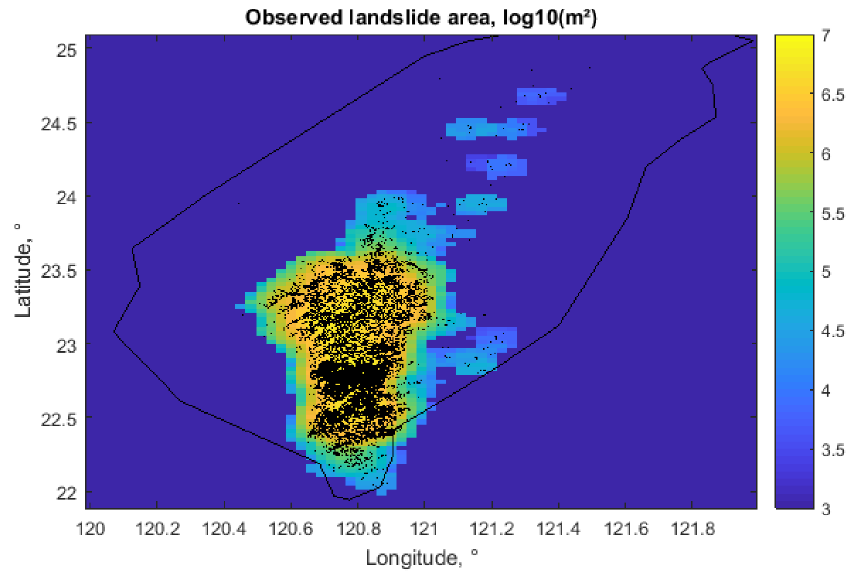
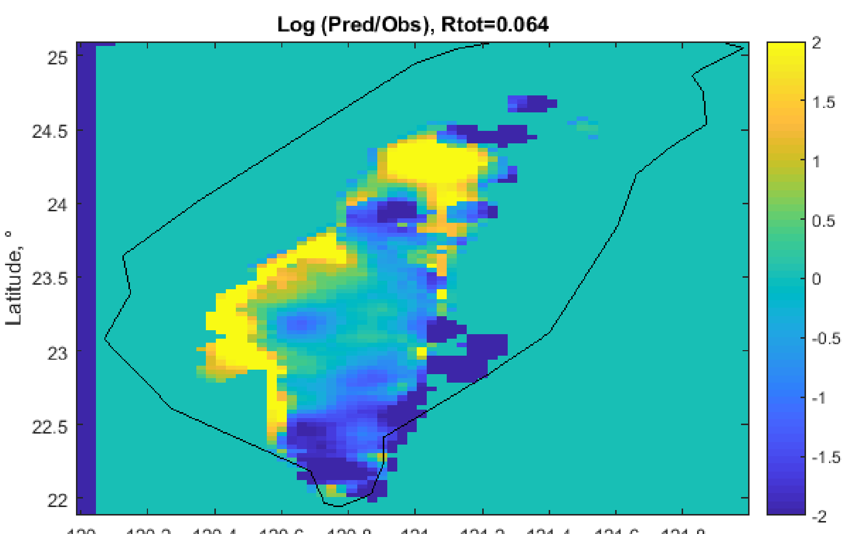
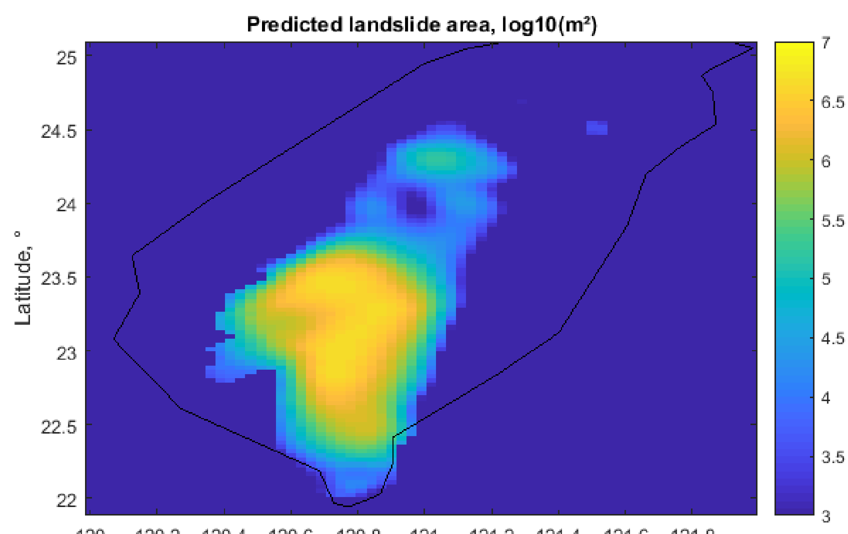
Probabilistic modelling of landslide pattern



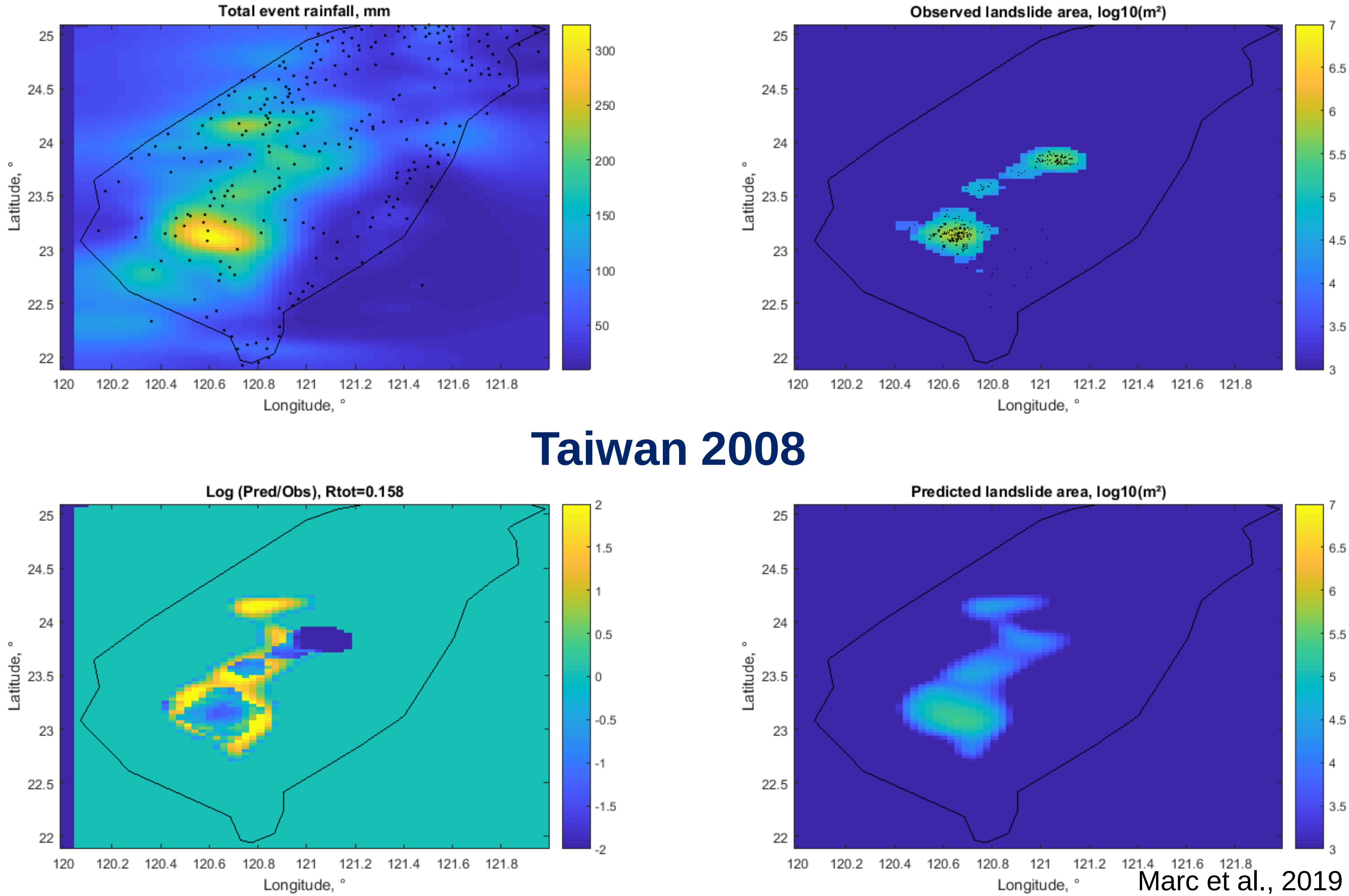


Taiwan 2009





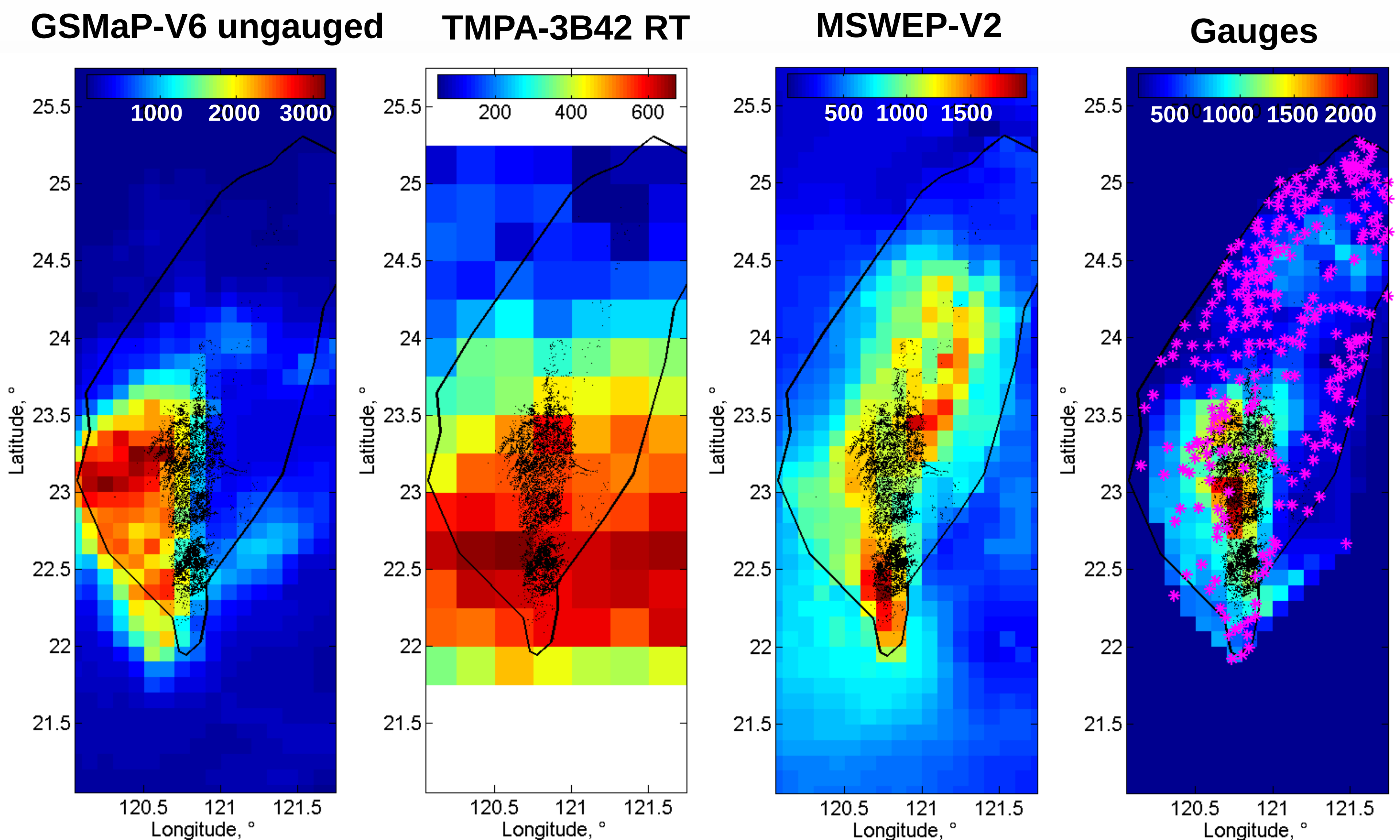
Probabilistic modelling of landslide pattern



Taiwan 2008

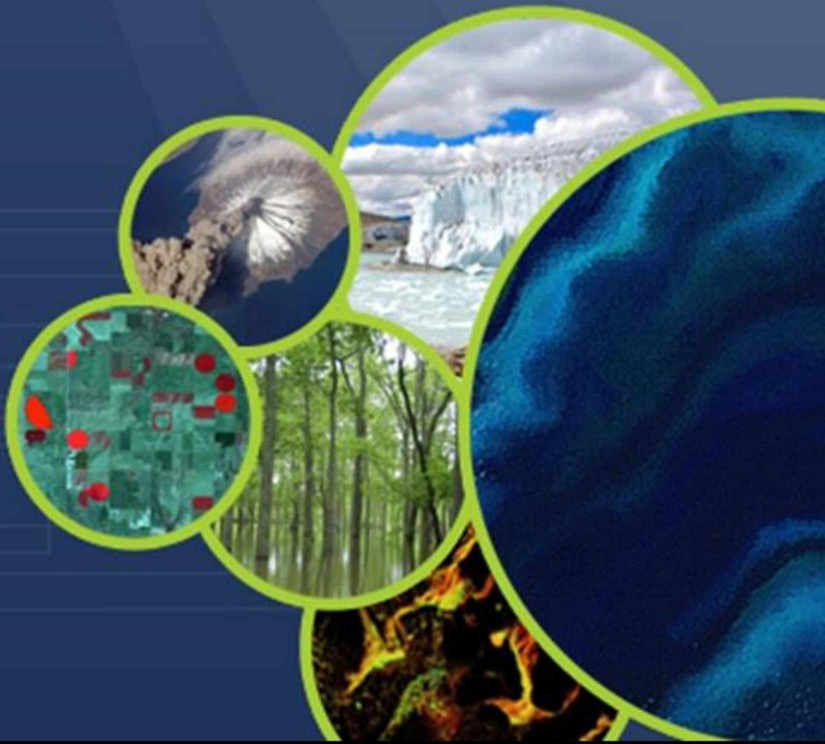
Marc et al., 2019

Be cautious with the Rainfall Satellite estimation



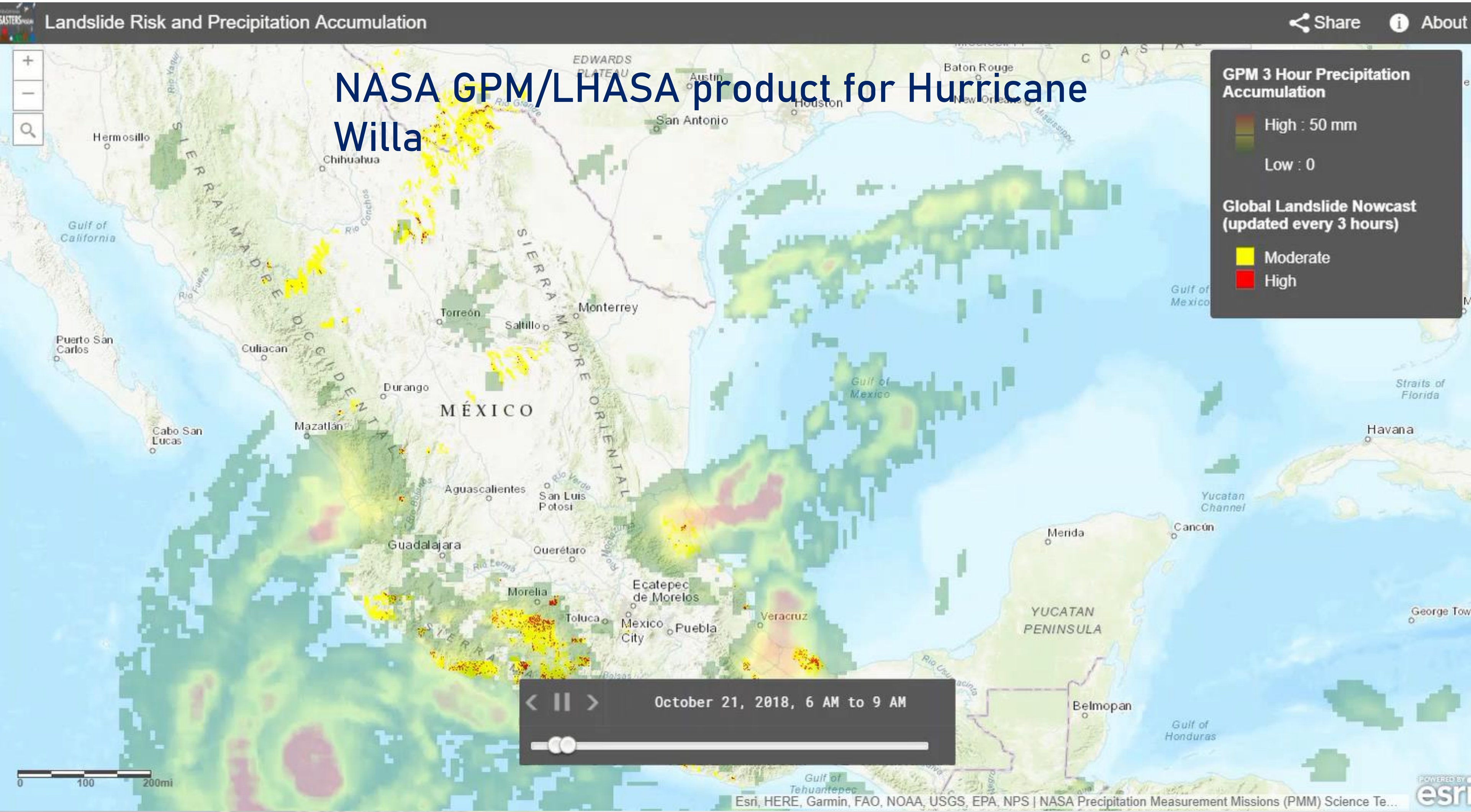
Global work

Landslide Hazard (and Risk)



Landslide Hazard Assessment for Situational Awareness (LHASA)

NASA GPM/LHASA product for Hurricane Willa



Kirschbaum and Stanley, 2018

https://maps.disasters.nasa.gov

LHASA-Rio

LHASA in action

The LHASA model has been integrated within the Alerta Rio emergency response network in the Rio de Janeiro Mayor's Office in Brazil.

Rio-LHASA model highlighted in Rio's Center of Operations for the City

"The new LHASA-Rio models provided us a framework where we can have real time results on landslide hazard situational awareness with the data that is available within the City Government."

– Felipe Mandarino, Instituto Pereira Passos

LHASA Rio in action for Nov 7th Rain Event

The automated real time model detected hazard of landslides for the first time at 9:45 pm of that night, with more than 50mm of rain being registered in an one-hour period at the Saúde rain gauge.

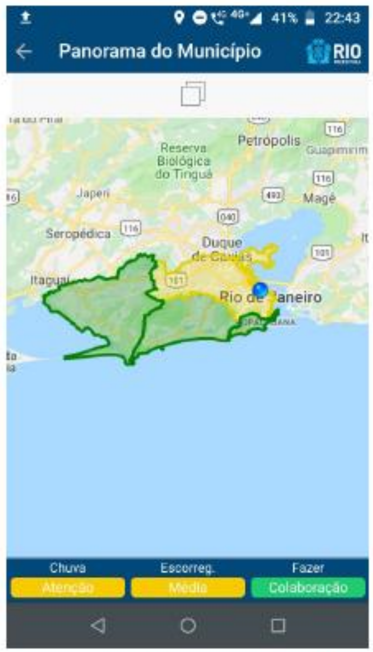


Figure 2 and 3. LHASA Rio real time output showing high (red) and moderate (yellow) landslide hazard on the Saúde region (2) and Alerta Rio app showing the alert issued at the same time (21:45 or 9:45 pm) for the whole Guanabara Bay Basin area (3).

The Alerta Rio system issued an alert for medium probability of landslides exactly at the same time, for the whole Guanabara Bay.

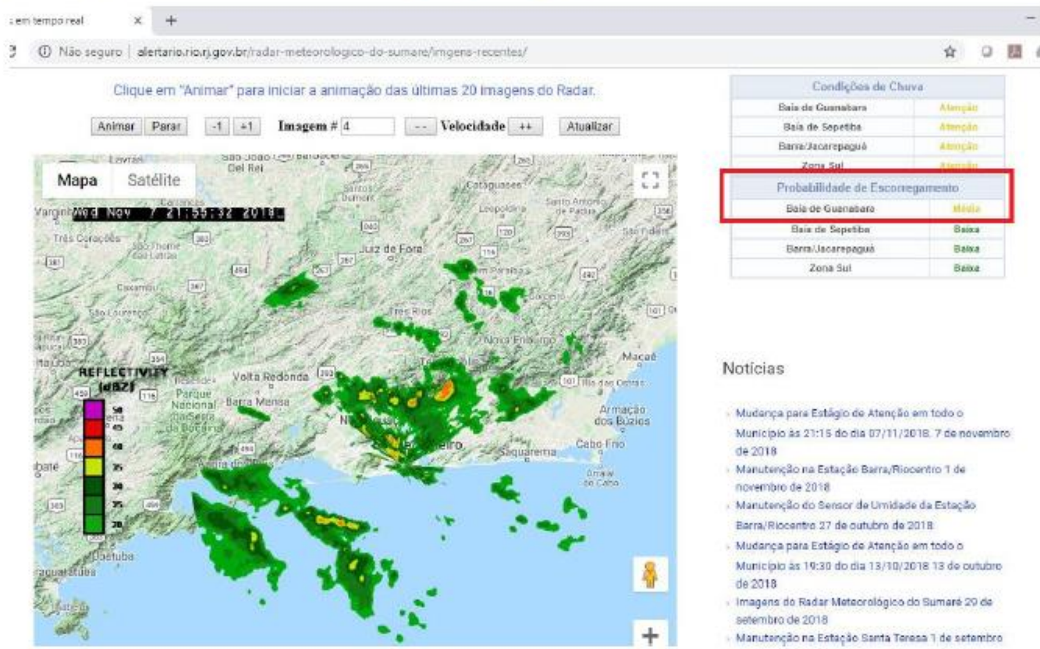
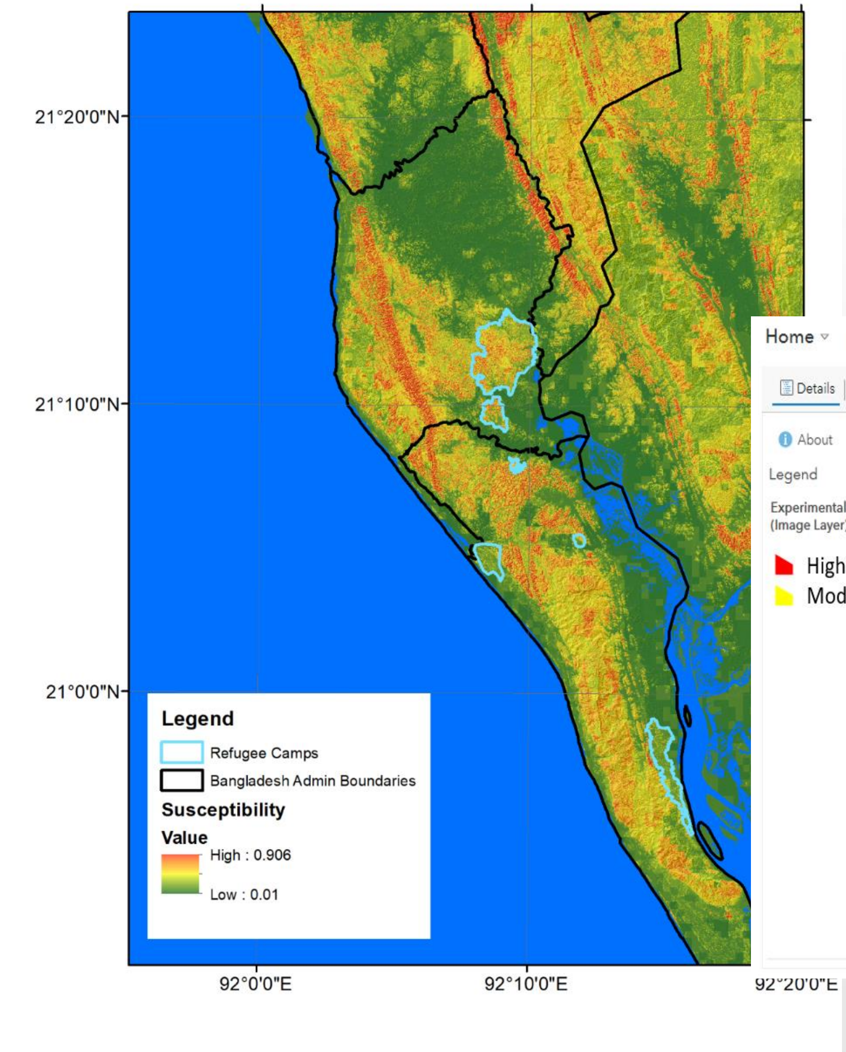
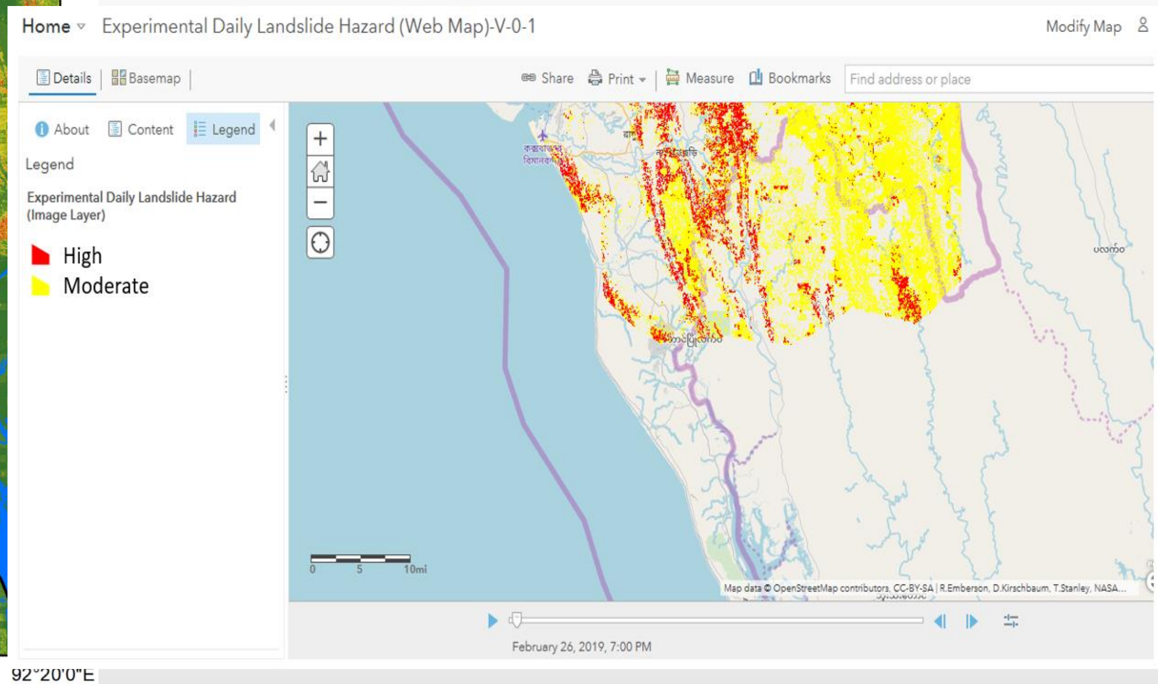


Figure 4. Screenshot from Alerta Rio website (http://alertario.rio.rj.gov.br) where can be seen a meteorological radar image from 9:55 pm and the alert issued for landslides at the Guanabara Bay Basin (highlight in the red box).

Bangladesh Local Mapping

- Development of local model products to estimate landslide hazard and exposure
- Developed in consultation with the UNDP IOM/UNHCR for direct application in the camps

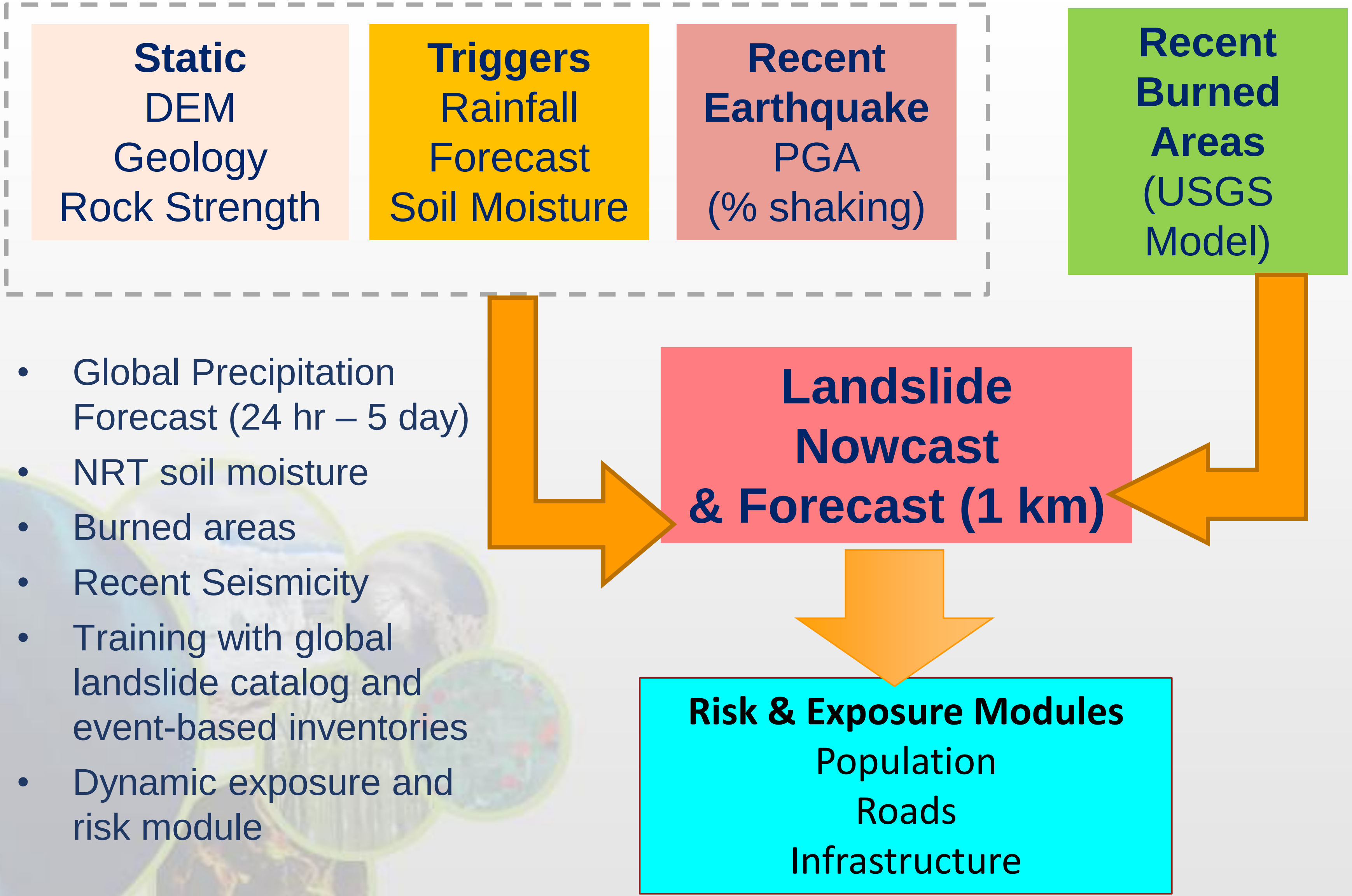




Emberson and Kirschbaum, in prep

LHASA 2.0
in development!

- Global Precipitation Forecast (24 hr – 5 day)
- NRT soil moisture
- Burned areas
- Recent Seismicity
- Training with global landslide catalog and event-based inventories
- Dynamic exposure and risk module



Pilot Deliverables

PILOT DELIVERABLE

DRAFT MANUSCRIPT ON-GOING

CEOS WG Disaster – Landslide Pilot – Draft review paper

Draft title:
Appropriate space-borne remote sensing techniques for landslide detection and monitoring: review and selection criteria

Possible authors
Kirschbaum Dalia, Amatya Pukar
Malet Jean-Philippe, Provost Floriane
Roessner Sigrid
Godt Jonathan

And all landslide pilot contributors who had access to data and did some processing
Olivier Dewitte, Antoine Dille
Georgina Bennett, James Christie
Alessandro Mondini
Alexander Handwerger, Eric Fielding, David Bekaert,
Matt O Bannion (? Any outputs from him?)
Jack Williams, Nick Rosser
Francesca Cigna, Teodato Tapete
and Chinese colleagues

Definitions: landslide inventory mapping vs. landslide monitoring and decision-aiding criteria

Landslide observation for mapping and for monitoring
Definition of the parameters/properties that could be extracted from the images …. Per category

Criteria to select the most appropriate space-borne technologies
The choice of the most appropriate space-borne technology is conditioned by a number of factors.

- Landslide-related criteria comprise the landslide type, size and expected displacement rates. External criteria include the configuration of the site, the surface conditions, financial and logistic constraints, the current risk management phase and the scientific objectives of the study.
- Technological criteria correspond to the capability of particular space-borne techniques. Technological criteria inherent to different monitoring techniques are the main focus of this review. The considered criteria are the detection and measurement accuracy, spatial coverage, temporal resolution, number of estimated parameters, costs for data acquisition and processing, expected elaboration time and complexity and maturity of the technique.

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Technological criteria

Criteria	Scale range	Explanation
Spatial coverage	Local (e.g. slope) Regional	Typical scales at which the measurements are carried out.
Information type	Landslide location	Geographical position of the landslide
	Landslide size	Geographical position and extent of the landslide
	Landslide volume	Volume of the landslide
	Landslide displacement fields	1D (one component of the displacement or change along a spatial axis or along the Line-Of-Sight -LoS- of the sensor), 2 displacement field), 3D (3D displac
	Landslide surface features	Time and space evolution of ty surface features (cracks , boulders
Spatial resolution	10^{-1} to 10^{2} m	Typical spacing of individual measu
Temporal resolution	Days to months	Typical time lag betwee measurements
Measurement accuracy	10^{-1} to 10^{2} m for size 10^{1} to 10^{3} m^{3} for volumes 10^{-1} to 10^{2} $m.day^{-1}$ for displacement rates	Accuracy of the measured quan displacement rates, volumes and surface features
Operation mode	Continuous – data flow type processing	Automatic calculation can be without human intervention f periods and for each new sensor i
	Campaigns – on-demand processing	Measurements require reg intervention and are thus typica intervals of several days, weeks or
Approximate elaboration time	minutes to days	Approximate time lag b measurement of the system and t of the output results.
Approximate costs	XXXX $	Typical costs including sensor da and processing
Technological maturity	Concept	Technical design and potential ap been proposed.
	Prototype	Working prototypes have been limited number of experiments.
	Case-studies	Operating systems have been tested for landslide applications for short time periods.
	Commercial	Working systems and processing softwares are

Landslide-related factors		
Landslide type Surface displacement rates Monitoring scale	Not applicable	The technique is not useful for this particular category.
	Probably not applicable	It is very unlikely that the technology is useful for this particular category, however exceptions may exist.
	Applicable in few cases	The technology could be applicable but restrictions must be expected. Alternatives should be considered.
	Suitable in many cases	The technology has been used in several case studies for the same landslide type/ displacement rate/ scale. Further criteria should be carefully checked before decision is made.
	Ideal in many cases	In many applications, this technology has provided excellent results for the same landslide type/displacement rate/scale.
External factors		
Surface conditions (bare soils, vegetation, snow, oil humidity, etc)	-	To be elaborated ….
Site configuration (slope gradient, slope direction, etc)	-	To be elaborated ….
Landslide motion		To be elaborated (e.g. mostly horizontal, mostly vertical, fully 3D; range of displacement rates)

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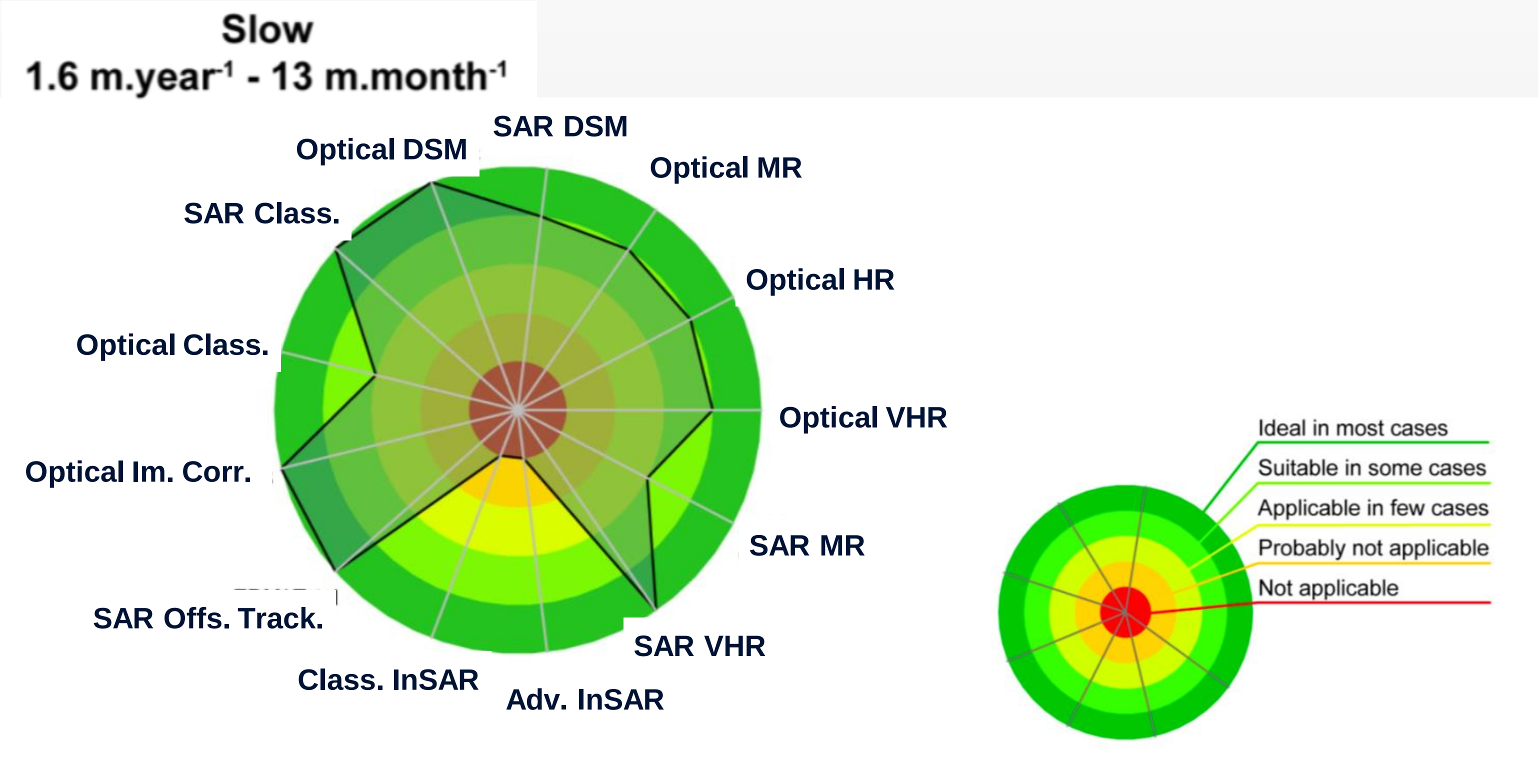
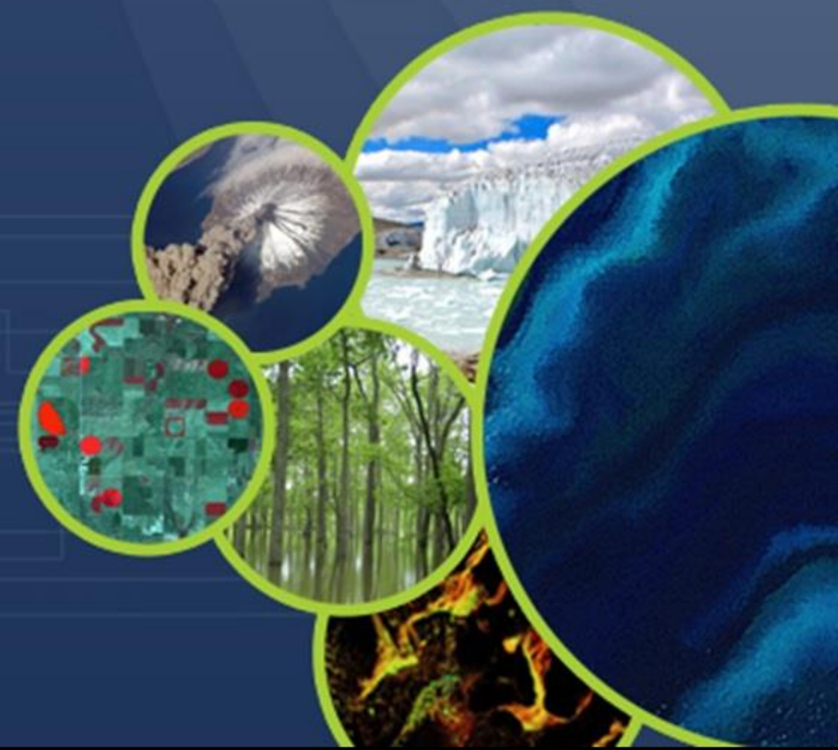
Guidelines for the selection of the appropriate space-borne technology
This section provides a detailed evaluation of the proposed criteria that can be used as rule sets for the choice of the most appropriate technique for different monitoring scenarios.



Landslide Demonstrator



WHAT'S NEXT
LANDSLIDE DEMONSTRATOR

Status at the end of the Pilot:

- Algorithms (surface motion, landslide detection): mature
- Models available (probabilsitic, deterministic) for several scales and topîcs (thresholds, hazard, exposure)
- HPC/Cloud processing available, some of them accessible to users. (e.g. GEP)

Proposed Landslide Demonstrator:

A demonstrator for the probabilistic modelling of thresholds, Hazard and Exposure for prioritizing insurance payout system (both country and municipality)

A demonstrator for the operational landslide monitoring of large traffic corridors (South America, Alps, maybe Canada)

A demonstrator to share and disseminate event-based landslide inventories at the global scale