



Committee on Earth Observation Satellites

# WG Disasters Geohazards Lab

Michael Foumelis (AUF)

Philippe Bally (ESA)

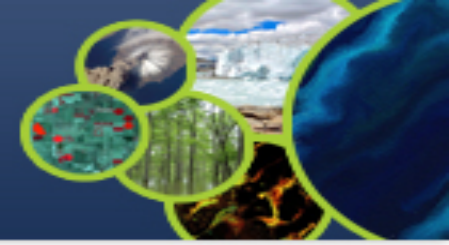
Jean-Philippe Malet (CNRS/EOST)

Fabrizio Pacini (Terradue)

WG Disasters 17 (virtual)

15, 16, and 17 March 2022

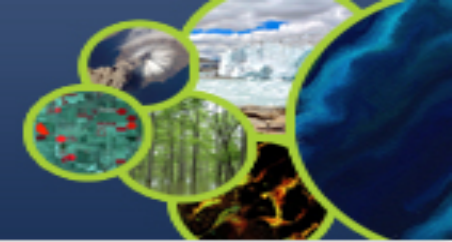




## A platform with federated resources to provide data access and an online processing and e-collaboration environment to exploit EO data to assess geohazards and their impact

- ✓ Supports and complements the CEOS WG Disasters thematic activities, GSNL and users from the broader geohazards community
- ✓ Maximize use of EO techniques and cloud processing by the EO expert community
- ✓ Achieve acceptance of EO products by the non-expert EO scientific community, non-EO downstream users and decision makers





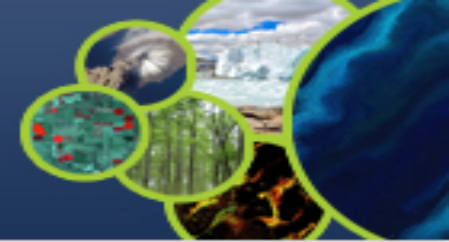
The GEP is a cloud-based environment providing a set of EO processing services that allow mapping hazard prone land surfaces and monitoring terrain motion.



**International Forum on Satellite EO and Geohazards**  
organized by ESA and GEO in Santorini in 2012 (140+ participants)

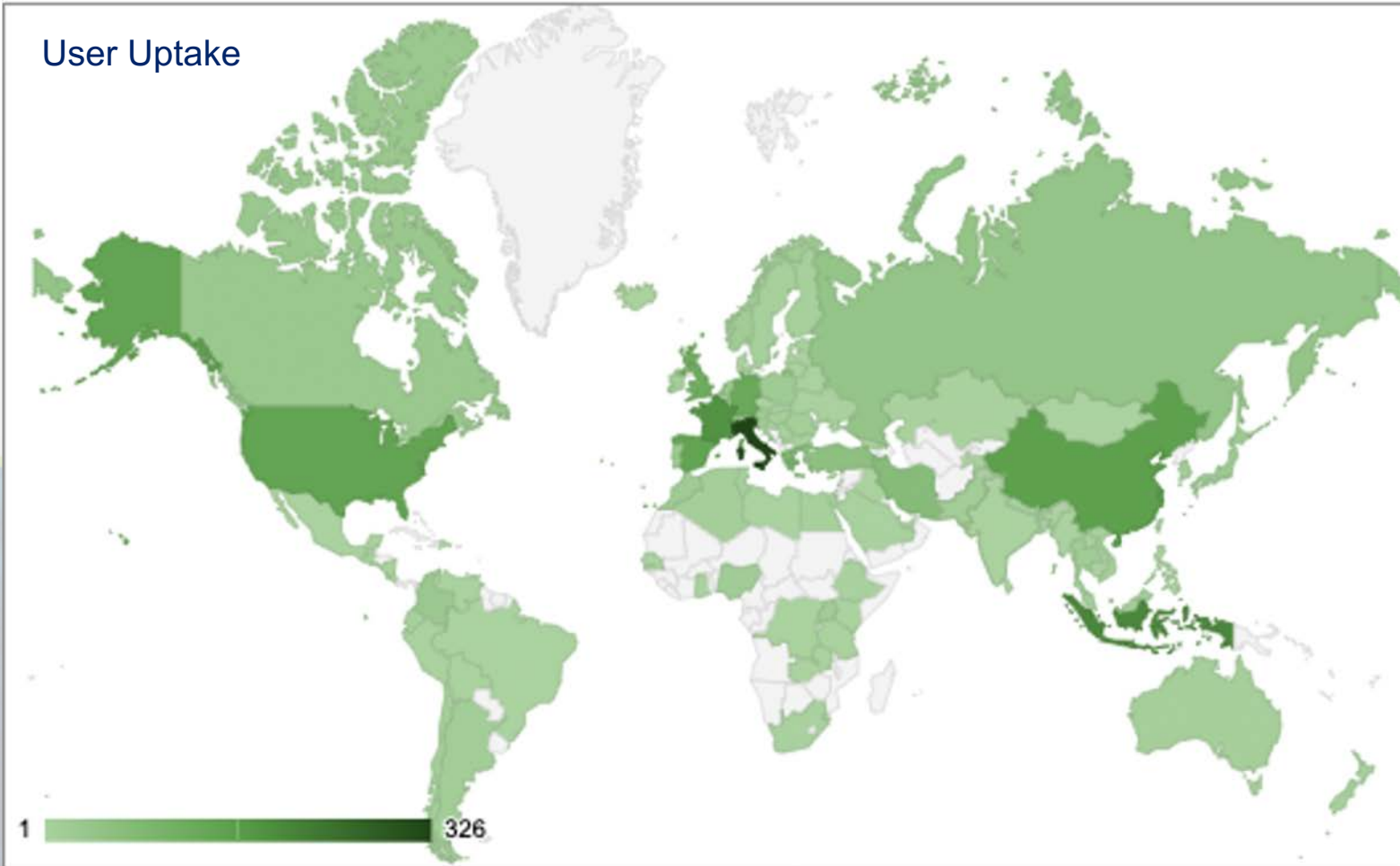


<p>thematic exploitation platform</p> <p><a href="https://tep.eo.esa.int">https://tep.eo.esa.int</a></p>	<p><b>geohazards</b> tep</p>	<p><b>polar</b> tep</p>	<p><b>coastal</b> tep</p>
	<p><b>hydrology</b> tep</p>	<p><b>urban</b> tep</p>	<p><b>forestry</b> tep</p>



## Pre-Operations Reporting Jan. 2022

### User Uptake

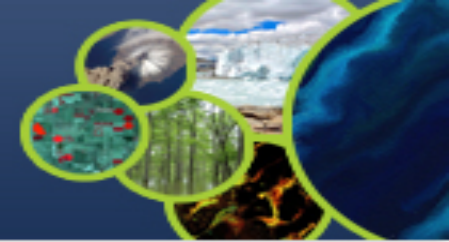


#	Country	#users
1	Italy	326
2	Indonesia	203
3	France	
4	China	
5	United States	
6	Spain	
7	Germany	
8	United Kingdom	
9	India	
10	Greece	
11	Iran	
12	Switzerland	
13	Turkey	
14	Russia	
15	Canada	
16	Colombia	
17	Netherlands	
18	Portugal	
19	Japan	
20	Austria	
21	Poland	
22	Morocco	
23	Thailand	
24	Norway	
25	Belgium	
26	Uganda	
27	Philippines	
28	Nigeria	
29	Pakistan	
30	Mexico	
31	Argentina	
32	South Korea	
33	Romania	
34	Brazil	
35	Taiwan	
36	Chile	
37	Algeria	
38	United Arab Emira	
39	Malaysia	
40	Singapore	

#	Country	#users
41	Ireland	10
42	Australia	10

#	Country	#users
82	India	2
83	Iceland	2
84	Dominican Republic	2
85	Dominica	2
86	Democratic Republic of the Con	2
87	Danemark	2
88	Czech Republik	2
89	Bolivia	2
90	Bhutan	2
91	Zambia	1
92	Trinidad & Tobago	1
93	Swaziland	1
94	Serbia	1
95	Senegal	1
96	Republic of Kosovo	1
97	Qatar	1
98	Philippine	1
99	Peru	1
100	Nicaragua	1
101	Myanmar	1
102	Mongolia	1
103	Malta	1
104	Lybia	1
105	Laos	1
106	Kenia	1
107	Guatemala	1
108	Guadalupe	1
109	Ghana	1
110	Georgia	1
111	El Salvador	1
112	Croatia	1
113	Costa Rica	1
114	Cambodia	1
115	Brasil	1
116	Birmaniam	1
117	Bielorussia	1
118	Azerbaijan	1
119	Armenia	1
120	Albania	1

**Grand Total 2546**



Overview

### Sample Dashboard for Apache logs

Simple dashboard for exploring & visualizing web traffic by analyzing Apache logs. This dashboard is included as a part of the [Getting Started with ELK](#) repo on Github.

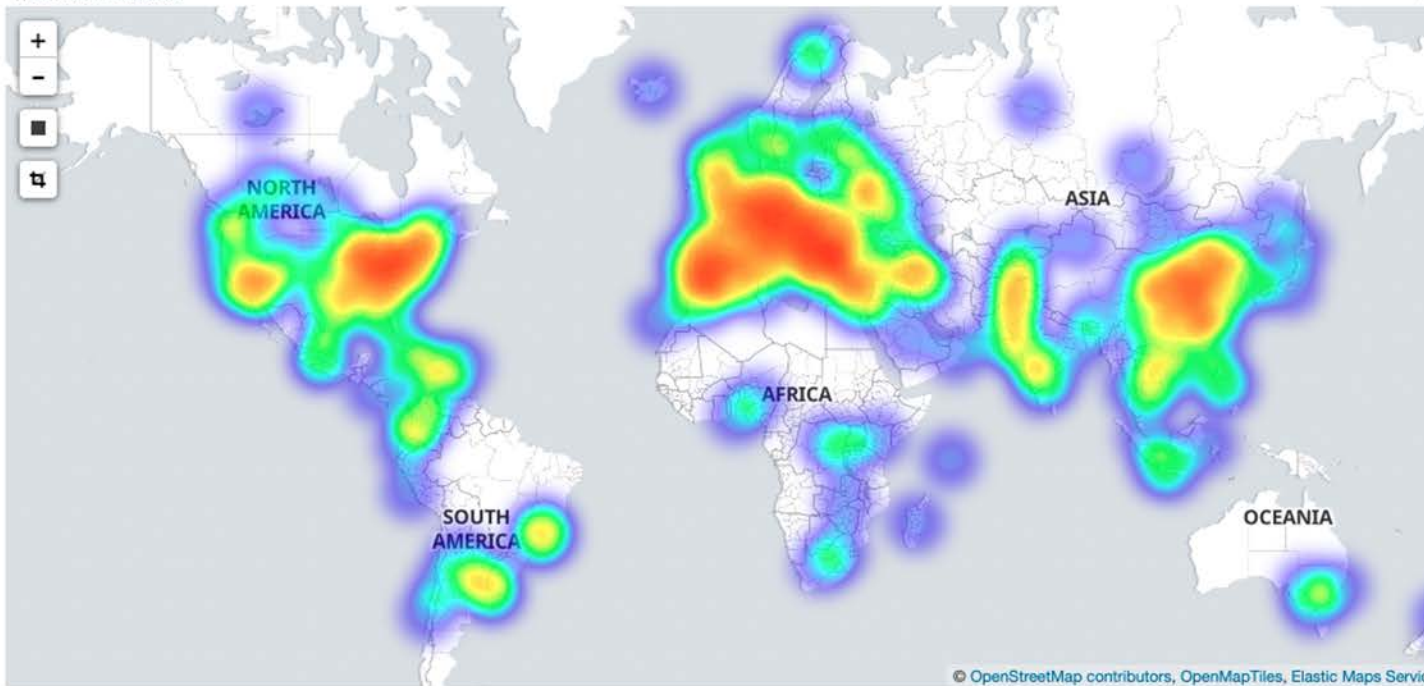
**Dashboard includes:**

- Number of unique visitors
- Map show # of hits by location
- Pie chart of traffic by device types
- Pie chart of traffic by operating systems

Feel free to explore & modify the dashboards to your hearts content. Ask questions, test hypothesis, diagnose issues!

**Happy exploration!!!**

Traffic vs. Location



Unique Visitors

Unique count of geoip.ip

**2,823**

Total Visitors

Count

**216,881**

Unique Visits by City

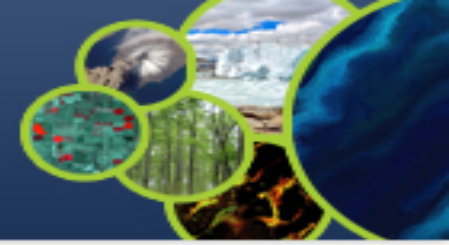
geoip.city_name: Descending	Unique count of clientip
San Francisco	180
Hangzhou	160
Boardman	77
Falls Church	31
Strasbourg	31
Beijing	26

Total Hits by City

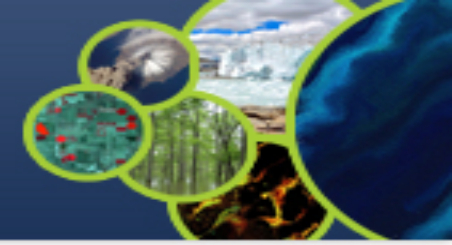
geoip.city_name: Descending	Count
Strasbourg	11,510
Rome	8,267
Toulouges	6,817
Chambly	5,376
Thermi	2,443
Madrid	2,320
Kukusan	2,306

Bytes vs. Time

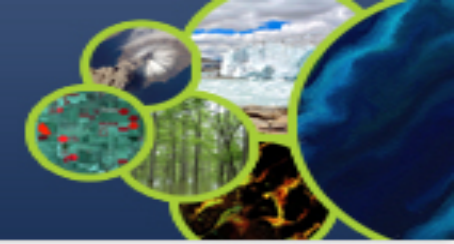




NoR Sponsored Users			
#	Organization	Country	Project
1	CNR IRPI	Italy	Seismogenic faults investigation and monitoring
2	AUTh	Greece	InSAR hosted services for monitoring pipelines
3	Charles University	Czech Republic	Determination of long-term post-seismic ground movements in L'Aquila (Italy) after the earthquake of 2009
4	National Observatory of Athens (IAASARS)	Greece	GEP products for Corinth Rift Laboratory activities
5	Politecnico Milano	Italy	Data for master thesis in statistics
6	AUTh	Greece	Wide Area InSAR Processing
7	CNRS - EOST AUTh Université de Strasbourg	France, Greece	Science support for satellite EO and geohazard risk assessment
8	Instituto Geológico y Minero de España (IGME)	Spain	AGEO project- Platform for Atlantic Geohazard Risk Management
9	CONAE	Argentina	Detection and analysis of landslides in the Sierras Pampeanas of Argentina using advanced methods in SAR remote sensing
10	Istituto Nazionale di Geofisica e Vulcanologia	Italy	Community Data Hosting for Exploitation (500Gb Pleiades)
11	Istituto Superiore per la Protezione e Ricerca Ambientale (ISPRA)	Italy	Ground Motion in Como area
12	INRAE	France	Exploiting InSAR for Mekong Subsidence
13	NARSS, Egypt	Egypt	Monitoring coastal subsidence in Egypt
14	ESUT, Agbani, Enugu	Nigeria	Processing of Sentinel-1 Data using SBAS method and other related method

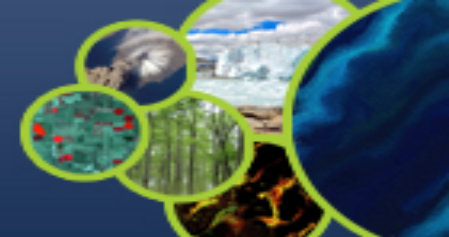


#	Organization	Country	Project
15	IMPACT Initiatives	Ukraine	Displacement Analysis in Toretsk Coal Mining Area (Eastern Ukraine)
16	Universidad Politécnica de Madrid	Spain	Active tectonics in SE Spain and El Salvador
17	Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Italy	Exploitation of the InSAR tools from the GEP Platform for ground deformation studies
18	ESA, CNR-IREA, University of Leeds, CalTech, Friedrich-Schiller-University Jena, Joanneum Research	Italy, UK, US, Germany	Sentinel-1 Extended Timing Annotation Processor - GEP hosting
19	Universidad Católica de Manizales	Colombia	DInSAR Analysis on Galeras and Chiles-Cerro Negro volcanoes (Sentinel-1 images)
20	European Space Agency	Italy	Sentinel-1 Extended Timing Annotation Processor
21	University of Lagos	Nigeria	Investigating and modelling land subsidence in parts of Nigeria
22	Instituto Geográfico Nacional (IGN)	Spain	GEP services to improve the Volcanic Monitoring System at Instituto Geográfico Nacional (Spain)
23	University of Huelva	Spain	Subsidence analysis of SW Spain
24	Center of Space Techniques (Algeria)	Algeria	Determination of land movement velocities at National scale (Algeria) by N-SBAS approach and Sentinel-1 data
25	University of Padova	Italy	Prevention of Potential Catastrophes Depending on Interferometric Radar Technique and Artificial Intelligence
26	National Research Council (CNR)	Italy	Monitoring land subsidence and its induced risk using advanced InSAR methods
27	University of Pisa	Italy	Crustal deformation monitoring
28	UNIZAR	Spain	Monitoring of sinkholes, large landslides and salt diapirs in the NE Spain



#	Organization	Country	Project
29	Geological Survey of Austria	Austria	GEORIOS - Local scale landslide detection and monitoring based on Sentinel-data
30	NOA Geodynamic Institute	Greece	Rapid analysis & study of surface deformation by earthquake & geohazard events
31	University of Houston	USA	Subduction in the North to Northwest Houston, Texas Area, USA
32	University of Liege	Belgium	EO for the monitoring of proglacial lakes and related hazards in high-mountain conditions - Landslide and GLOFs detection and monitoring
33	University of Granada	Spain	Monitoring ground instability in Southern Spain
34	Alberta Geological Survey	Canada	Monitoring ground motion using Sentinel-1 data over landslide susceptible areas and abandoned coal mines in Alberta, Canada
35	Sapienza University of Rome	Italy	Applications of differential interferometryDInSAR for monitoring ground deformations and Civil infrastructures
36	Czech Geological Survey	Czech Republic	Detection of long-term subsidence across Czech Republic
37	Istituto Nazionale di Geofisica e Vulcanologia	Italy	Geodetic and seismological observations
38	Istituto Nazionale di Geofisica e Vulcanologia	Italy	Community Data Hosting for Exploitation (9TB CSK)
39	NORCE Norwegian Research Centre AS	Norway	AVAMAP - Automatic snow avalanche detection using Sentinel-1
40	European Space Agency	Italy	Sentinel-1 Extended Timing Annotation Processor
41	Istituto Nazionale di Geofisica e Vulcanologia	Italy	Monitoring of different hazards and environmental impact due to human activities and natural phenomena by means of remote sensing data
42	Carleton University / Environment and Climate Change	Canada	Sentinel-1 InSAR for peatland ecosystem mapping





# Recent Developments





# ESA Charter Mapper

INTERNATIONAL CHARTER SPACE & MAJOR DISASTERS SATELLITE DATA TO SUPPORT DISASTER RESPONSE WORLDWIDE

- To support the Charter PM and the VA in the context of activations, the COS-2 system has been augmented with a processing environment to access EO data on-line and perform visual and GIS analysis and basic EO processing

- Access the Charter Mapper:

<https://cpe.disasterscharter.org>

- The User Manual:

<https://docs.disasterscharter.org>

- Same underlying platform as the GEP (chains and products can be shared)

ESA Charter Mapper  
Welcome to the Charter Processing Environment implemented under the responsibility of the European Space Agency. It is built and integrated in COS-2 to support operations with on-line access to EO data.

[Act-734/Call-844] Flood in Thailand  
Sep 28th 2021 3 months ago  
Call Id 844  
Status open  
Open Workspace

ESA Charter Mapper [Act-734/Call-844] Flood in Thailand

Acquisitions Datasets VA Products My Results TEST\_ESA\_M4rcance

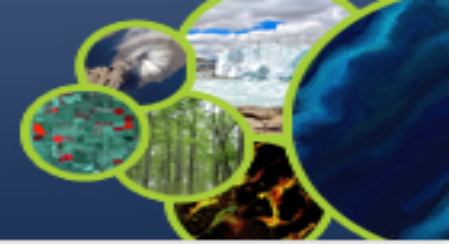
Filter Criteria  
Satellite Sensor type  
Date Range Resolution  
Search

Context Datasets  
Results for series [chartercalibrateddataset(callid844)]

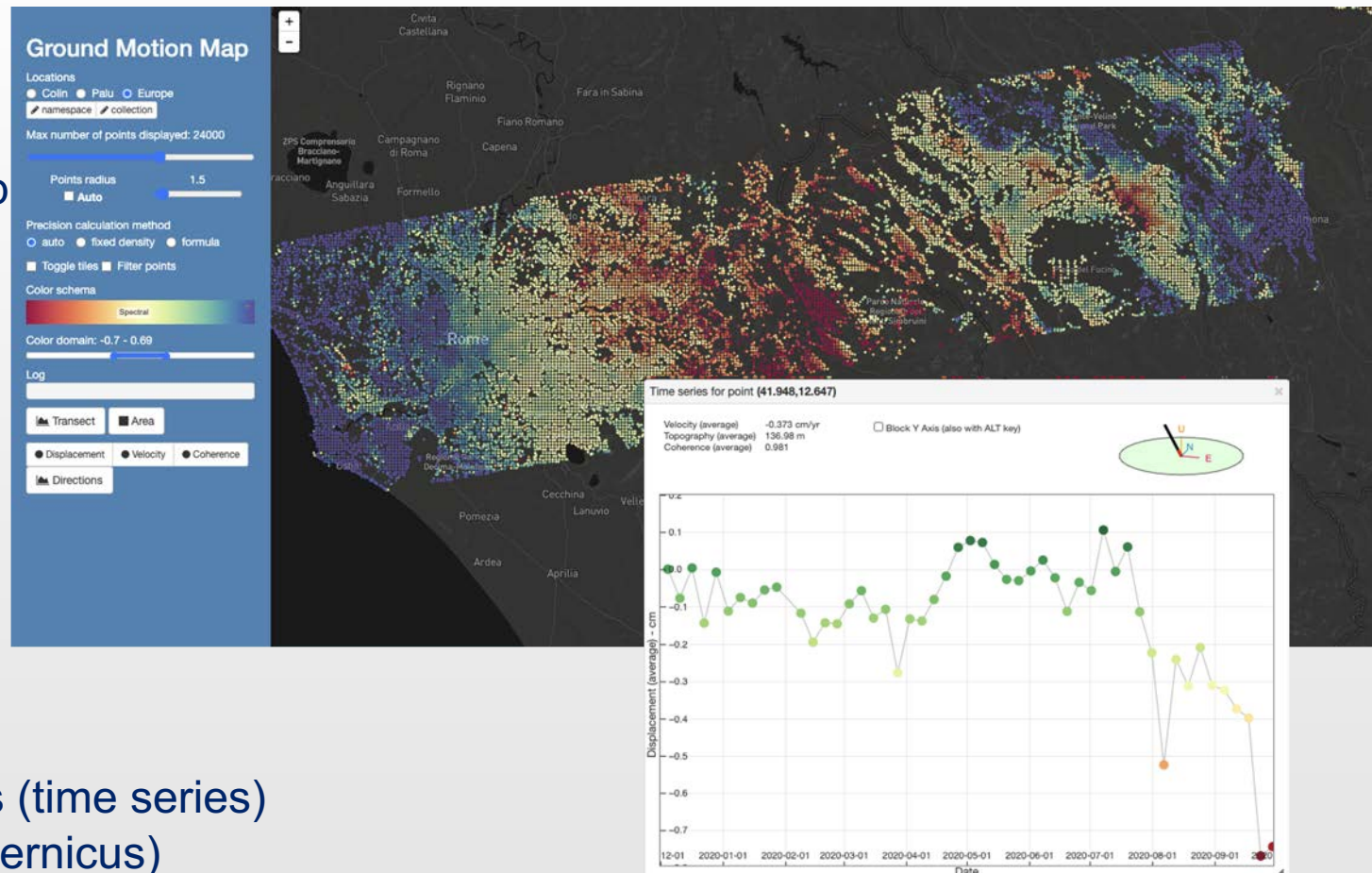
Acquisition	Satellite	Sensor type	Date Range	Resolution
[EO] VRSS-1 WMC-2 L2B 2021/11/20 01:51:28	VRSS-1	WMC-2	L2B 2021/11/20 01:51:28	10m
[EO] VRSS-1 WMC-1 L2B 2021/11/20 01:51:23	VRSS-1	WMC-1	L2B 2021/11/20 01:51:23	10m
[EO] VRSS-1 WMC-2 L2B 2021/11/20 01:51:05	VRSS-1	WMC-2	L2B 2021/11/20 01:51:05	10m
[EO] VRSS-1 WMC-1 L2B 2021/11/20 01:51:00	VRSS-1	WMC-1	L2B 2021/11/20 01:51:00	10m
[EO] VRSS-1 WMC-2 L2B 2021/11/20 01:50:43	VRSS-1	WMC-2	L2B 2021/11/20 01:50:43	10m
[EO] DEYE-X2 X-SAR Stripmap VV 16060 2021/11/12 03:31:23	DEYE-X2	X-SAR Stripmap	VV 16060 2021/11/12 03:31:23	10m
[EO] SENTINEL-1B CSAR DW VVHH 26 2021/10/24 11:12:38	SENTINEL-1B	CSAR DW VVHH 26	2021/10/24 11:12:38	10m
[EO] SENTINEL-1B CSAR DW VVHH 26 2021/10/24 11:12:13	SENTINEL-1B	CSAR DW VVHH 26	2021/10/24 11:12:13	10m
[EO] SENTINEL-1A CSAR DW VVHH 99 2021/10/23 11:21:45	SENTINEL-1A	CSAR DW VVHH 99	2021/10/23 11:21:45	10m
[EO] SENTINEL-1A CSAR DW VVHH 99 2021/10/23 11:21:20	SENTINEL-1A	CSAR DW VVHH 99	2021/10/23 11:21:20	10m
[EO] SENTINEL-1A CSAR DW VVHH 91 2021/10/22 22:52:48	SENTINEL-1A	CSAR DW VVHH 91	2021/10/22 22:52:48	10m
[EO] SENTINEL-1A CSAR DW VVHH 91 2021/10/22 22:52:23	SENTINEL-1A	CSAR DW VVHH 91	2021/10/22 22:52:23	10m

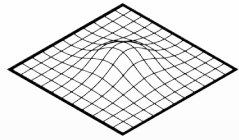
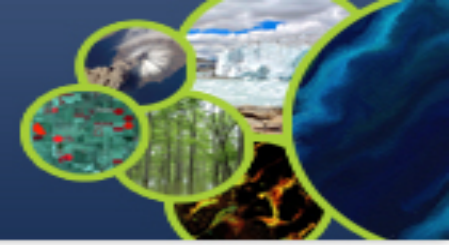
Total results: 154





- New Plugin for querying & viewing terrain motion pixels in the geobrowser with integrated functions
  - Time Series (one or more pinpoints selection)
  - Profile Analysis (line selection)
  - AOI Statistics (polygon selection)
  
- Allows the user adjust rendering of data map
  - Data map layers selection
  - Color scale adjustment
  
- Many export formats supported
  - CSV, KML and shapefiles for a limited area
  - PDF for a given data selection
  
- Inputs supported
  - P-SBAS, SNAPPING PSI
  - MPIC-OPT-SLIDE, -ICE
  - EGMS Time Series
  
- Improves visualization of advanced products (time series) and including Third Party products (e.g. Copernicus)

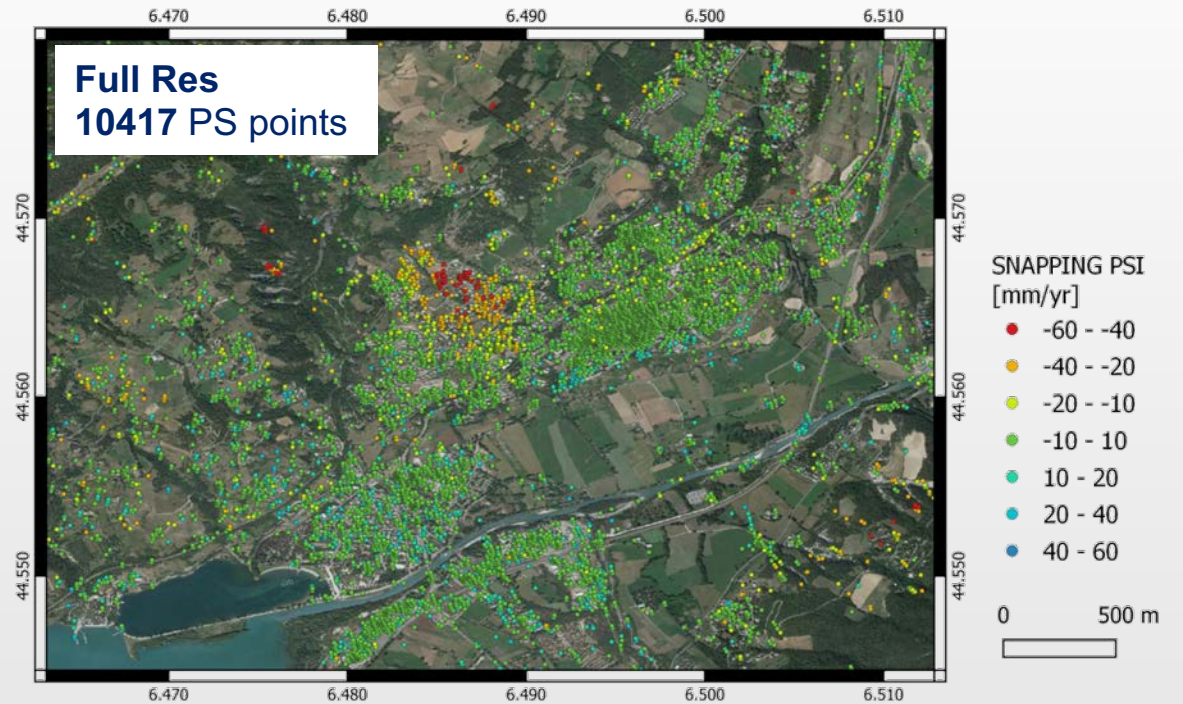
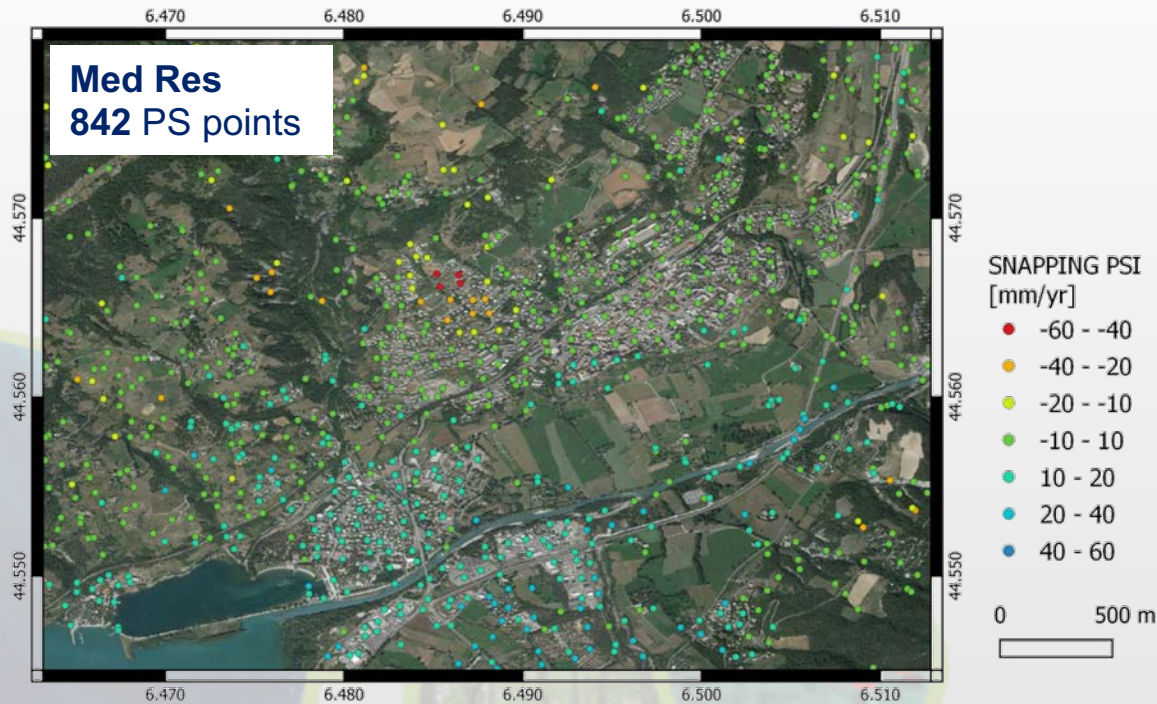


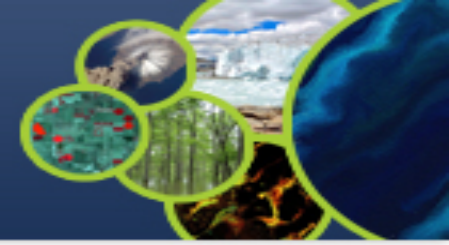


**SNAPPING**  
SURFACE MOTION MAPPING

SNAPPING | Surface motion mAPPING is a multi-temporal interferometric service for measuring terrain motion based on Persistent Scatterers Interferometry (PSI) technique using Copernicus Sentinel-1 mission data

SNAPPING Full Res version has been integrated and currently being internally tested (open to users Q2 2022)



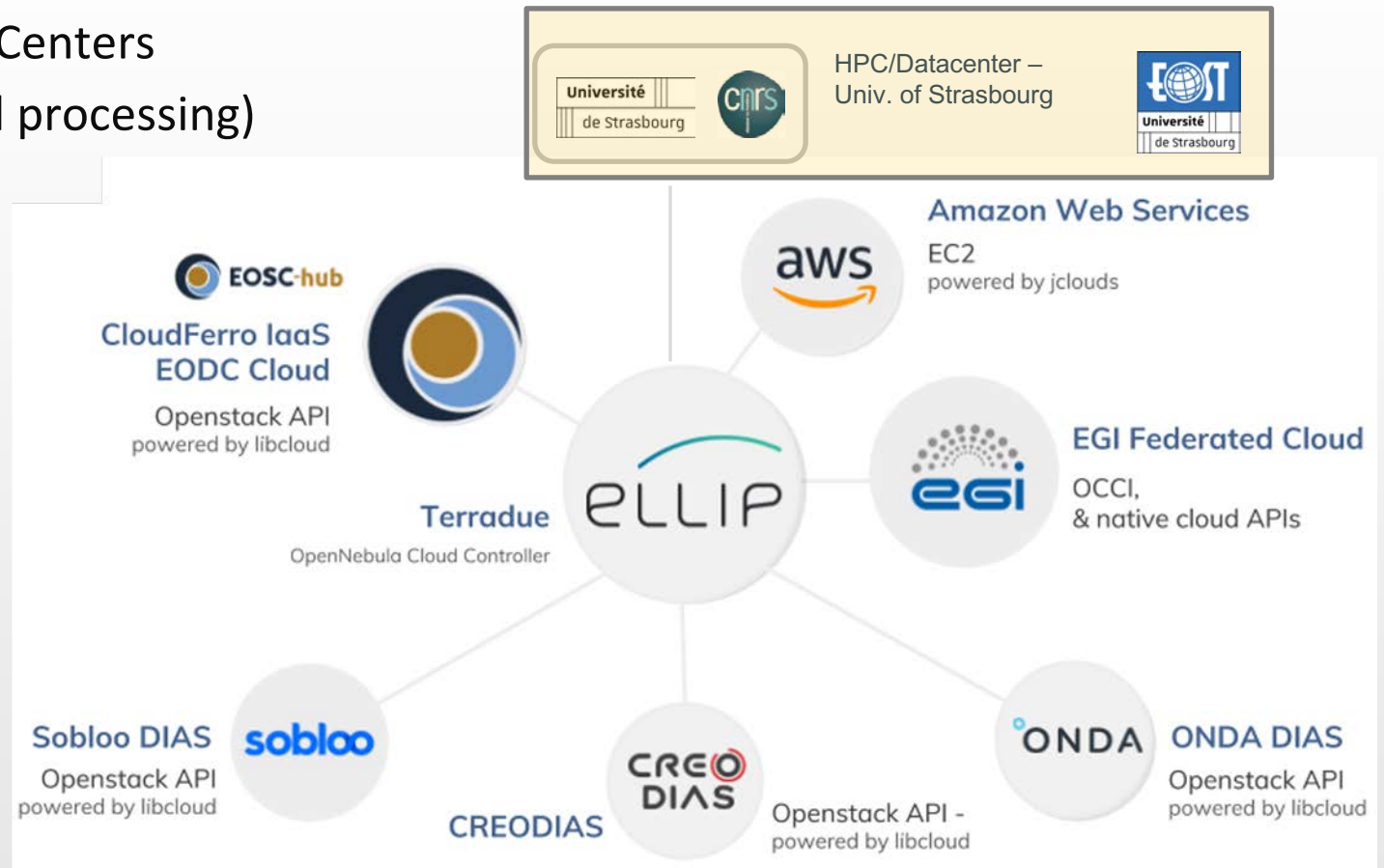


Ground motion services & other processing services of University of Strasbourg / HPC Production Centers are exposed through the GEP (for on-demand processing)

- Cost-effective data processing
- Pure HPC production center
- Easy maintenance and update of the code
- Better scalability of the resources

○ Processing services

- MPIC-OPT (ETQ, SLIDE, ICE)
- ALADIM HR / VHR
- DSM-OPT
- FLOW-R / VolToo
- LHS



# GEP | New modelling services to help understand/forecast hazards

## eo4alps-landslides App: Modelling Landslide Propagation

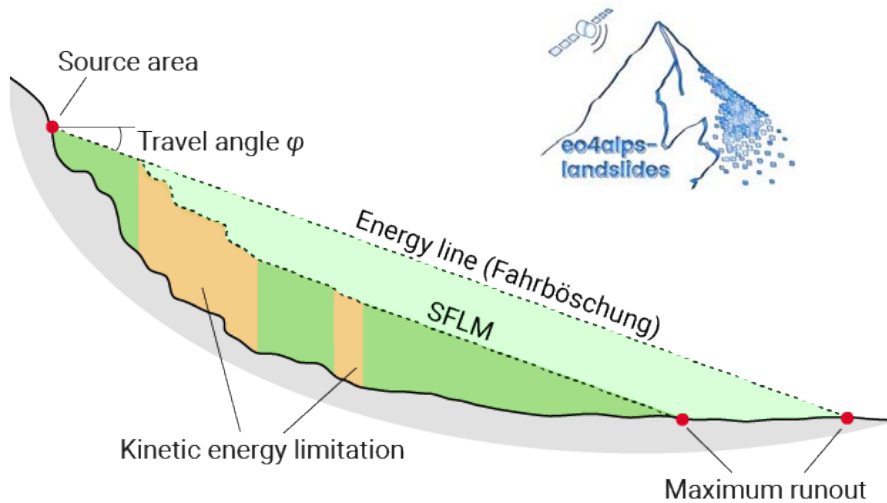
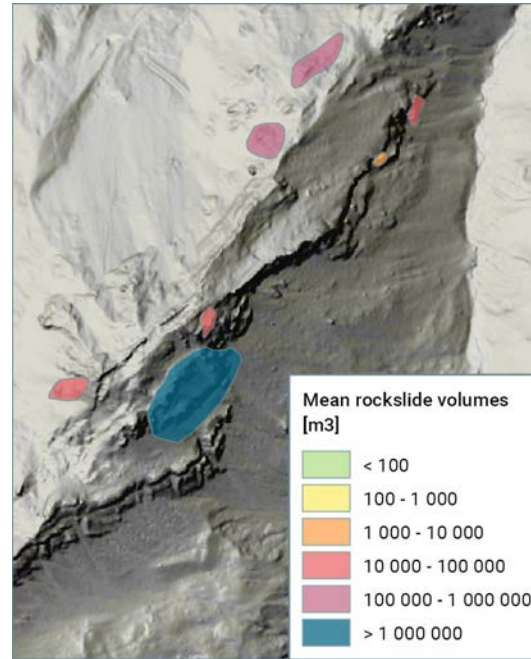


Illustration of the reach angle principle for modelling landslide propagation from geodatabases and high resolution relief

EO based services can contribute to the definition of landslide inventories & sources (e.g. MPIC, SNAPPING)

Assesment of mean volume of inventoried slope instabilities



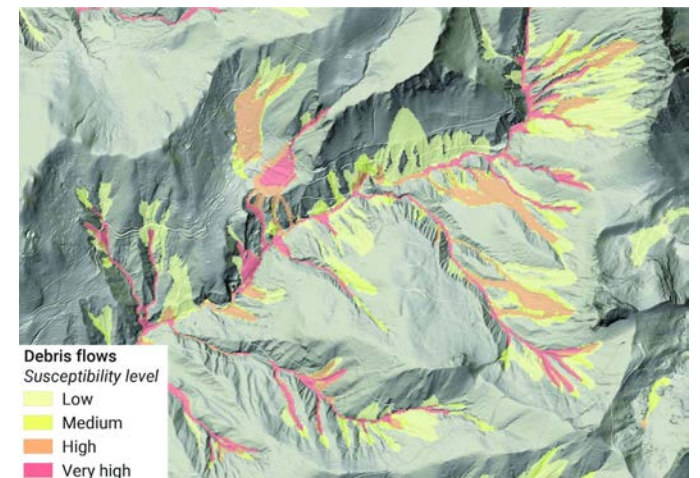
Step 1:  
**VolToo** for volume modelling



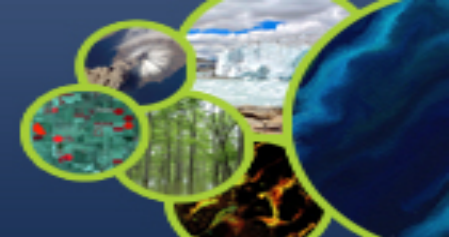
Step 2:  
**FLOW-R** for propagation/hazard modelling



10m Copernicus DSM used to model landslide runouts

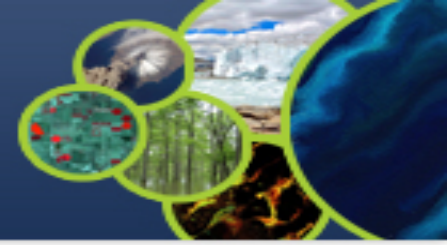


Extent of landslide runout areas



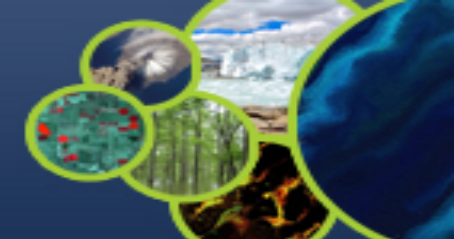
# Activities' Overview





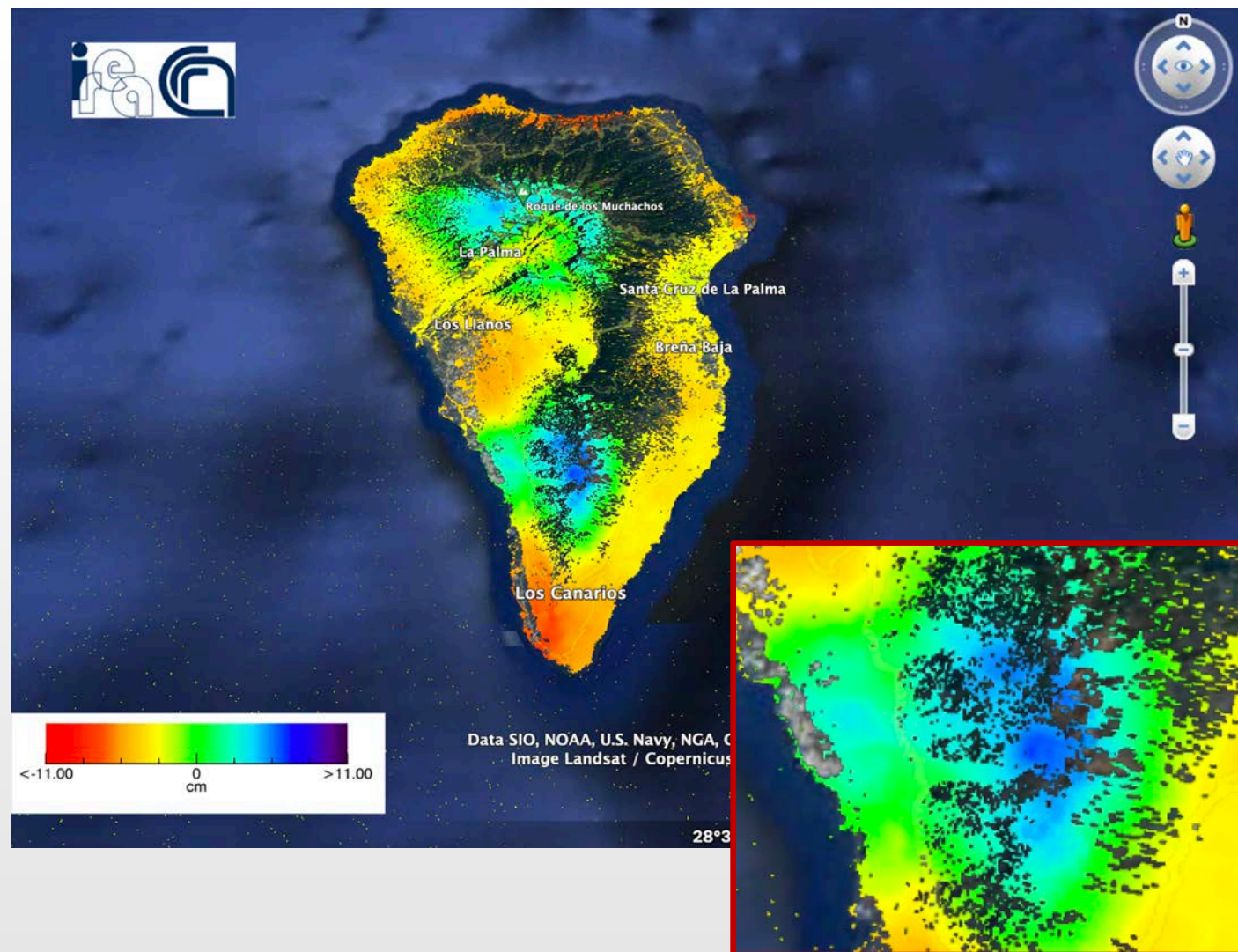
- GEP selected by EPOS for geospatial data cataloguing to support its user communities across Europe
- Demonstration of GEP services in International Development projects (EO-AID GDA, ADB, H2020)
- Nationally mandated geo-science centers from Europe have initiated subscription for GEP service
- Inter-verification of advanced GEP InSAR services (P-SBAS & SNAPPING)
- Standardization/Harmonization activity *put on hold* given in view of relevant activities
- Moving forward with GEP governance (policies & rules)





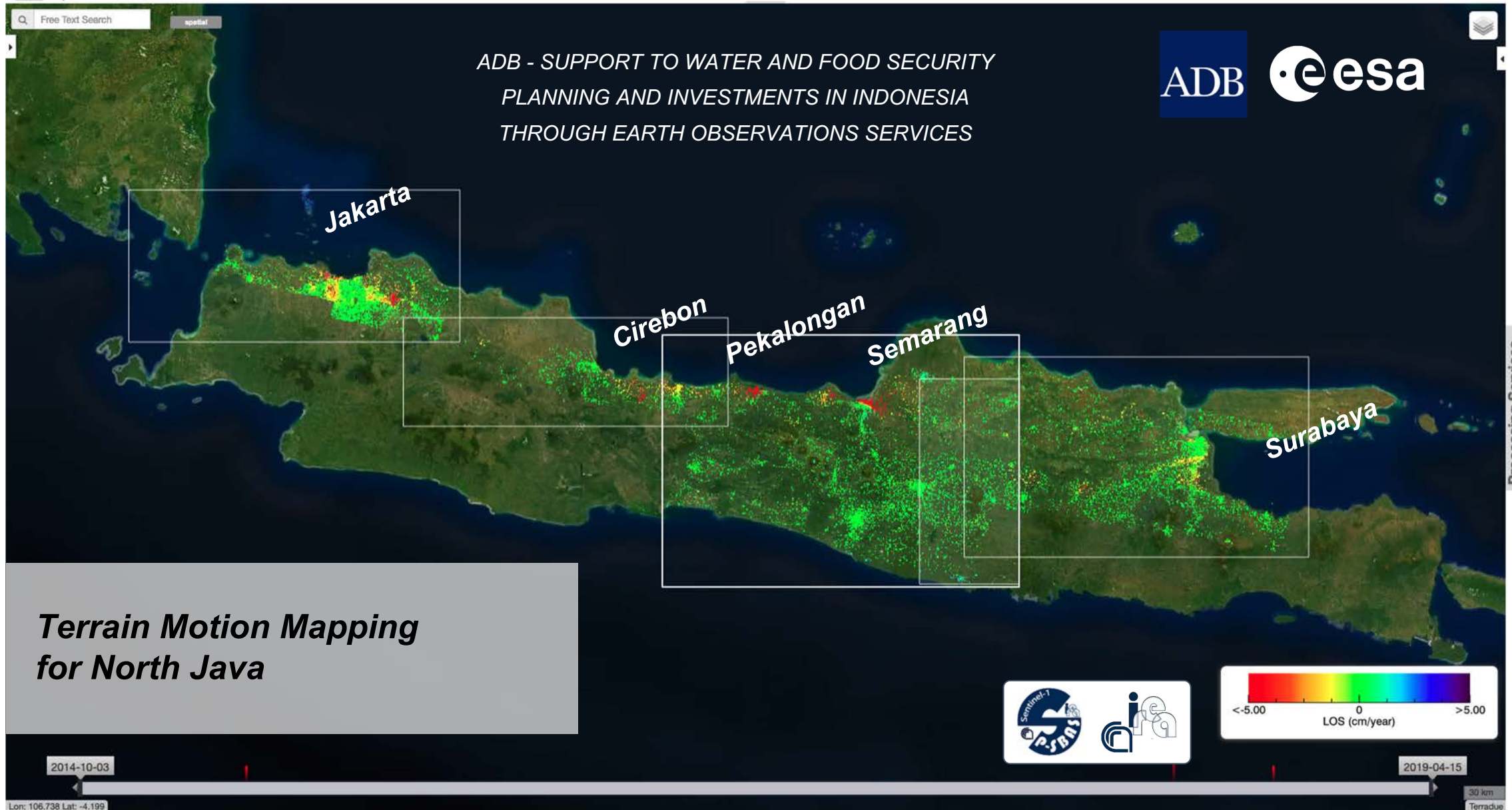
Prototype product created by *Floriane Provost* of the ESA project SAT looking at geohazard applications based on the Geohazard Exploitation Platform GEP. Terrain motion map based on the SBAS chain of CNR IREA (IT) and using Sentinel-1 SLC acquisitions.

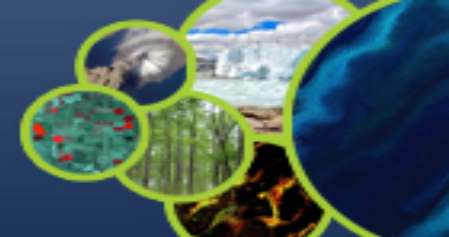
Comment: A signal of 10 cm uplift over Cumbre Veija volcano area (insert) can be seen and it appears correlated to the event while other signals appear accross the territory but their correlation isn't confirm and would require detailed assesment.



# ADB - Support to Water & Food Security Planning & Investments in Indonesia through EO Services

## North Java | GEP P-SBAS On-Demand InSAR Service

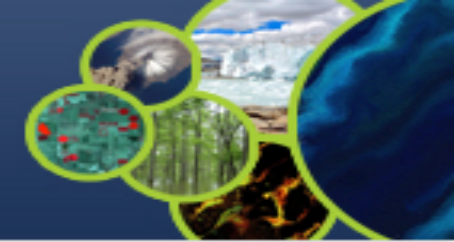




# Outreach & Capacity Building



- Several communications to social media (mainly blog posts and twitter)
- Publishing in scientific journals and participation to international conference and workshops (Applied Science; Remote Sensing; LPS 2022; IGARSS 2022)
- Multiple training and capacity building activities for the adoption of platform-based solution in scientific investigations and operational frameworks.

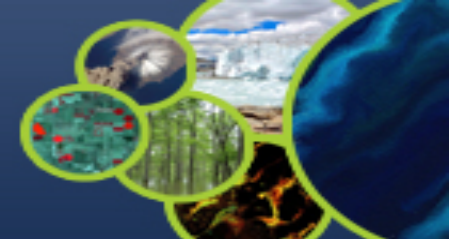


### List of Organized Activities:

- SFU / Canada
- RMCA / Belgium
- AIT / Indonesia (for ADB)
- Los Alamos National Laboratory / US
- University of Exeter / UK
- University of Padova / IT
- FSEC / Fonds de Solidarité Évènements Catastrophiques - Maroc
- L'Università di Pisa / IT
- AUTH / GR
- Sorbonne University Abu Dhabi (SUAD) / UAE
- National Authority For Remote Sensing & Space Sciences (NARSS) / Egypt
- AIT / Indonesia (for ADB)
- ESA-NASA Trans-Atlantic-Training (TAT) 2021
- SUAD Master Course
- Training Sessions with Multiple Users (DZ, FR, GR, ID, IT, UK, UAE etc.) organized by T2

### List of Pending Activities:

- BGC / Vancouver / Canada
- UGA / ISTERRE / France
- NIEP / Bucharest
- IGAR - UB - NMA - NIHWM - IGR - TUCCEB / Bucharest
- IVAR / Azores / Portugal
- GNS / New Zealand
- IGOT / UL / Portugal
- CSIC / Spain



Research Paper

Correspondence to:  
Vasilios Karakostas  
vkar@cees.auth.gr

DOI number:  
http://dx.doi.org/10.12681/cees.27237

Keywords:  
seismic sequence, fault-slip  
step model, seismological  
geodesy, stress transfer and  
triggering

Citation:  
Karakostas, V., Papazachos, C., Papadimitriou, E., Fomellis, M., Kiratzi, A., Párlidas, C., Kostoglou, A., Kouskalis, C., Chatzi, N., Bitharis, S., Chatzipetros, A., et al. (2021), The March 2021 Tyranos, Central Greece, Doublet (M<sub>w</sub>6.3 and M<sub>w</sub>6.0): Aftershock Relocation, Faulting Details, Cosismic Slip and Deformation. *Bulletin Geological Society of Greece*, 58, 131-178.

Publication History:  
Received: 09/06/2021  
Accepted: 18/08/2021  
Accepted article online:  
24/08/2021

The Editor wishes to thank  
two anonymous reviewers for  
their work with the scientific  
reviewing of the manuscript  
and Ms Emmanouela  
Konstantakopoulou for  
editorial assistance

©2021. The Authors.  
This is an open access  
article under the terms of the  
Creative Commons  
Attribution License, which  
permits use, distribution and  
reproduction in any medium,  
provided the original work is  
properly cited.

Geological Society of Greece

Volume 58

## THE MARCH 2021 TYRANOS, CENTRAL GREECE, DOUBLET (M<sub>w</sub>6.3 and M<sub>w</sub>6.0): AFTERSHOCK RELOCATION, FAULTING DETAILS, COSEISMIC SLIP and DEFORMATION

Vasilios Karakostas<sup>1</sup>, Constantinos Papazachos<sup>1</sup>, Eleftheria Papadimitriou<sup>1</sup>, Michael Fomellis<sup>2</sup>, Anastasia Kiratzi<sup>1</sup>, Christos Párlidas<sup>2</sup>, Anastasios Kostoglou<sup>1</sup>, Charalambos Kkallas<sup>1</sup>, Nikolaos Chatzi<sup>1</sup>, Stylianos Bitharis<sup>1</sup>, Alexandros Chatzipetros<sup>1</sup>, Aristidis Fotiou<sup>1</sup>, Chriantith Ventouzi<sup>1</sup>, Eleni Karagianni<sup>1</sup>, Pavlos Bonatzi<sup>1</sup>, Christos Kourouklas<sup>1</sup>, Parthena Paradiropoulou<sup>1</sup>, Emmanouil Scordiliadis<sup>1</sup>, Domenikos Vamvakaris<sup>1</sup>, Ioannis Crendas<sup>1</sup>, Despoina



## Sentinel-1 Big Data Processing with P-SBAS InSAR in the Geohazards Exploitation Platform: An Experiment on Coastal Land Subsidence and Landslides in Italy

Francesca Cigna<sup>1</sup> and Dorothea Tapete<sup>1</sup>

Italian Space Agency (ASI), Via del Politecnico 150, 00133 Rome, Italy; dorothea.tapete@isi.it

\* Correspondence: francesca.cigna@isi.it

**Abstract:** The growing volume of synthetic aperture radar (SAR) imagery acquired by satellite constellations creates novel opportunities and opens new challenges for interferometric SAR (InSAR) applications to observe Earth's surface processes and geohazards. In this paper, the Parallel Small Baseline Subset (P-SBAS) advanced InSAR processing chain running on the Geohazards Exploitation Platform (GEP) is trialed to process two unprecedentedly big stacks of Copernicus Sentinel-1 C-band SAR images acquired in 2014–2020 over a coastal study area in southern Italy, including 299 and 283 scenes in ascending and descending mode, respectively. Each stack was processed in the GEP in less than 3 days, from input SAR data retrieval via registration, up to generation of the output P-SBAS datasets of coherent targets and their displacement histories. Use cases of long-term monitoring of land subsidence at the Cape Colonna promontory (tip ~2.3 cm/year vertical and ~1.0 cm/year east-west rate), slow-moving landslides and erosion landforms, and deformation at modern coastal protection infrastructure in the city of Crotone are used to: (i) showcase the type and precision of deformation products outputting from P-SBAS processing of big data, and the desirable key information to support value-adding and geological interpretations; and (ii) discuss potential and challenges of big data processing using cloud/grid infrastructure.

**Keywords:** SAR; radar interferometry; InSAR; SBAS; Sentinel-1; ground deformation; big data; high-performance computing; subsidence; landslides

### 1. Introduction

The last three decades have witnessed the increasing and widespread use of satellite synthetic aperture radar (SAR) imagery to retrieve key information on surface deformation processes affecting the Earth's surface using two- and three-pass differential interferometric SAR (InSAR) (e.g., [1–3]), and multi-pass/multi-temporal InSAR methods, such as persistent scatterers interferometry (PSI) (e.g., [4,5]) and Small Baseline Subset (SBAS) (e.g., [6–7]). Many SAR constellations have been developed since the 1990s and, as part of their background observation scenarios, have been tasked to acquire images regularly over major cities, targets with economic and/or strategic relevance (e.g., key infrastructure, polar regions, cultural heritage sites), regions affected by specific Earth hazards (e.g., tectonic zones and volcanoes), and entire nations or continents (e.g., [8,9]).

This means that the volume of SAR data collected to date, archived, and available for InSAR applications by far falls within the “big data” remit for such type of imagery (typically, 15–20 SAR scenes are needed as minimum input of an advanced InSAR analysis, e.g., [3]), and usually a few to several tens of scenes are used in most InSAR applications), thus creating novel opportunities and opening new challenges for Earth sciences and observation (e.g., [10,11]). For instance, since the beginning of its operations in late 2014, the Copernicus Sentinel-1 SAR constellation acquired over each area of Europe around 300 passes for each geometry, i.e., ascending and descending, with an initial repeat pass of 12 days with Sentinel-1A only (~180 scenes in 6 years), which was improved to 6 days in



## The Detection of Active Sinkholes by Airborne Differential LiDAR DEMs and InSAR Cloud Computing Tools

Jeniss Guerrero<sup>1,\*</sup>, Jorge Sevilla<sup>1</sup>, Gloria Deza<sup>1</sup>, Francisco Gutiérrez<sup>1</sup>, Angel Garcia Araya<sup>1,2</sup>, Jorge Pedro Galve<sup>2,3</sup> and Cristina Reyes-Camano<sup>2,3</sup>

<sup>1</sup> Departamento de Ciencia de la Tierra, Universidad de Zaragoza, C/Pedro Cerbuna 12,

50009 Zaragoza, Spain; jguerrero@zaragoza.es (J.S.); gdeza@zaragoza.es (G.D.); fgtier@zaragoza.es (F.G.); araya@zaragoza.es (A.C.A.)

<sup>2</sup> Departamento de Geomatika, Universidad de Granada, Avda. del Hospicio, s/n, 18010 Granada, Spain;

jgalve@ugr.es (J.P.G.); creyesc@ugr.es (C.R.C.)

<sup>3</sup> Correspondence: jguerrero@zaragoza.es; \* jguerrero@zaragoza.es

**Abstract:** InSAR (Interferometric Synthetic Aperture Radar) cloud computing and the subtraction of LiDAR (Light Detection and Ranging) DSM (Digital Elevation Model) use innovative approaches to detect subsidence in karst areas. InSAR cloud computing allows for analyzing C-band Envisat and Sentinel-1 SAR images through web platforms to produce displacement maps of the Earth's surface in an easy manner. The subtraction of aerial LiDAR DEMs results in the same product but with a different level of accuracy and precision than InSAR maps. Here, we analyze the capability of these methods to detect active sinkholes in the modeled carbonate basin of the Tieso Valley (NE Spain).



## The 27 September 2021 Earthquake in Central Crete (Greece)—Detailed Analysis of the Earthquake Sequence and Indications for Contemporary Arc-Parallel Extension to the Hellenic Arc

Emmanuel Vassiliakīs<sup>1,\*</sup>, George Kaviris<sup>1</sup>, Vasilis Kapetanidis<sup>1</sup>, Elena Papageorgiou<sup>1</sup>, Michael Fomellis<sup>1</sup>, Alki Kosmolaki<sup>1</sup>, Stelios Petrakis<sup>1</sup>, Christos P. Evangelidis<sup>1</sup>, John Aleopoulos<sup>2</sup>, Vasilios Karastathis<sup>3</sup>, Nicholas Voulgaris<sup>4</sup> and Gerassimos-Akhis Tselentis<sup>1,4</sup>

<sup>1</sup> Section of Geography and Climatology, Department of Geology and Geoenvironment, School of Sciences, National and Kapodistrian University of Athens, Pausaniasstr. Zografos, 15701 Athens, Greece; emmanuel.vassiliakis@geology.uoa.gr (E.V.); geokaviris@geology.uoa.gr (G.K.); vkapetanidis@geology.uoa.gr (V.K.); jaleopoulos@geology.uoa.gr (J.A.); steliospetrakis@geology.uoa.gr (S.P.)

<sup>2</sup> Section of Geophysics-Geochronology, Department of Geology and Geoenvironment, School of Sciences, National and Kapodistrian University of Athens, Pausaniasstr. Zografos, 15701 Athens, Greece; geokaviris@geology.uoa.gr (G.K.); vkapetanidis@geology.uoa.gr (V.K.); jaleopoulos@geology.uoa.gr (J.A.); steliospetrakis@geology.uoa.gr (S.P.)

<sup>3</sup> Department of Physical and Environmental Geography, Aristotle University of Thessaloniki (AUTH), 54124 Thessaloniki, Greece; elenapapageorgiou@auth.gr (E.P.); mfo@auth.gr (M.F.)

<sup>4</sup> Institute of Geodynamics, National Observatory of Athens, Lefon Symbion, 11850 Athens, Greece; evoulgaris@igw.uoi.gr (N.V.); karastathis@igw.uoi.gr (G.A.)

**Featured Application:** Field validation of combined remote sensing and seismological data after a large earthquake.

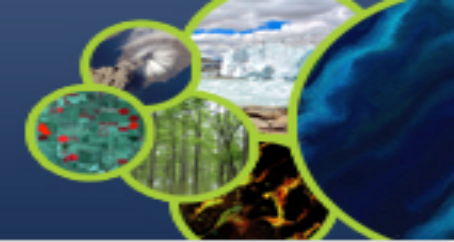
**Abstract:** The Arkalochori village in central Crete was hit by a large earthquake (M<sub>w</sub> = 6.0) on 27 September 2021, causing casualties, injuries, and severe damage to the infrastructure. Due to the absence of apparent surface rupture and the initial focal mechanism solution of the seismic event, we initiated complementary, multi-disciplinary research by combining seismological and remote sensing data processing, followed by extensive field validation. Detailed geological mapping, fault surface measuring accompanied with tectonic analysis, fault photoelastic model creation by unmanned aerial system data processing, post-seismic surface deformation analysis by InSAR image interpretation coupled with accurately relocated epicenters recorded by locally established seismographs have been carried out. The combination of the results obtained from these techniques led to the determination of the contemporary tectonic stress regime that caused the earthquake in central Crete, which was found compatible with extensional processes parallel to the Hellenic arc.

**Keywords:** Arkalochori; Messara Basin; Heraklion Basin; Kavalli fault zone; supra detachment basin; fault segmentation; double-difference relocation; InSAR

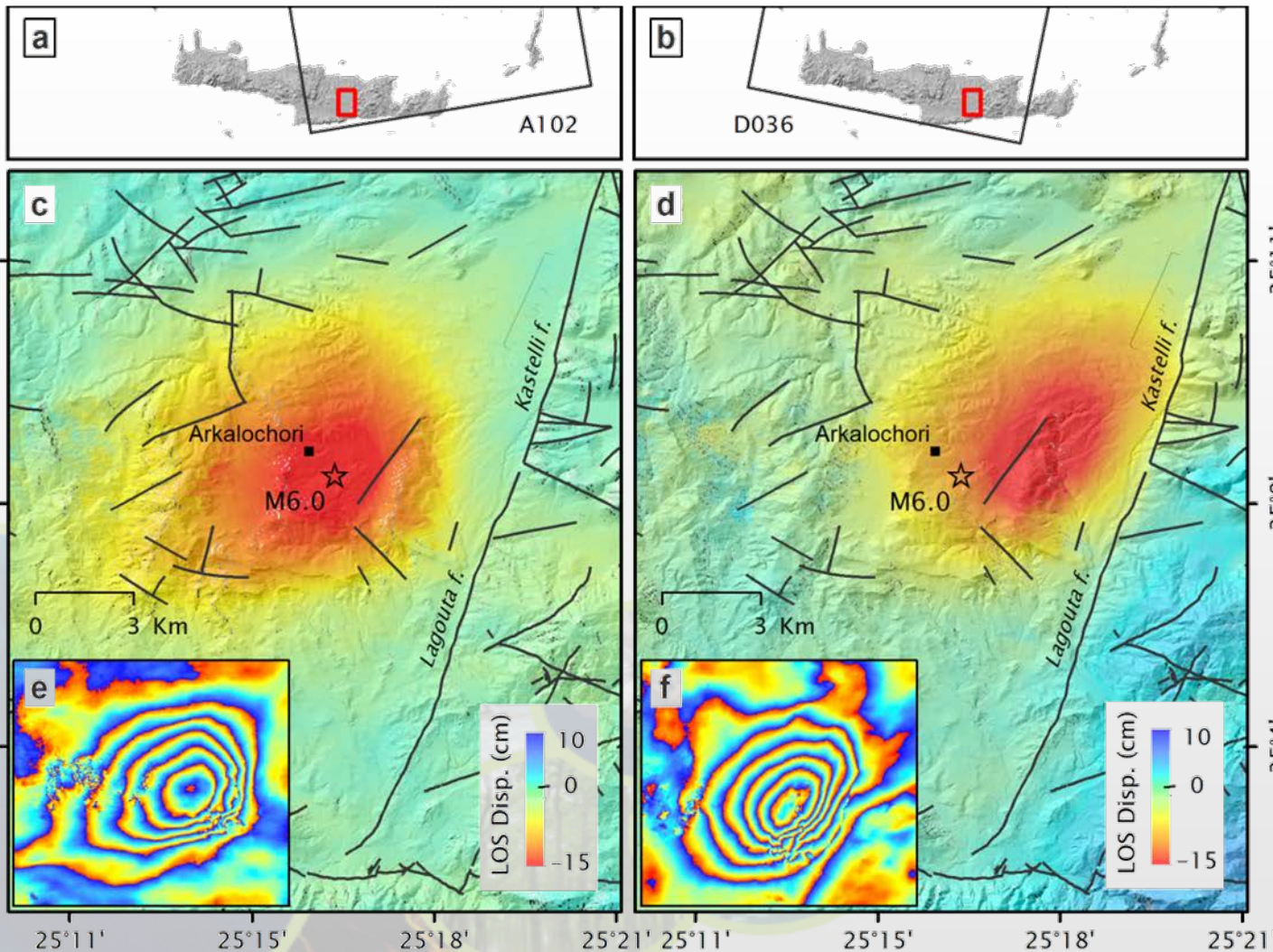
### 1. Introduction

The broader area of central Crete represents a neotectonic structure in the vicinity of the Hellenic Trench, which comprises two post-orogenic basins with trending orientations normal to each other, forming a uniform basin complex [1]. The northernmost part of the latter, the Heraklion Basin (HB), trends approximately N-S, whereas adjacent to its southern margin, the Messara Basin (MB) developed trending E-W [2,3]. We refer to this area as the Heraklion-Messara Basin complex, as it is covered by the same Miocene formations, implying that it shares a common paleo-environmental history, even though there are significant structural differences between the two basins.

- ❖ Several publications in scientific journals
- ❖ Contributions to ESA Living Planet Symposium
- Algerian Space Agency (ASAL), Algeria
- Aristotle University of Thessaloniki (AUTH), Greece
- Asian Institute of Technology (AIT), Indonesia
- CNRS/EOST, France
- CRL (ENS & NOA), France/Greece
- Indra, Spain
- National Authority for Remote Sensing and Space Sciences (NARSS), Egypt
- Sorbonne University Abu Dhabi (SUAD), UAE

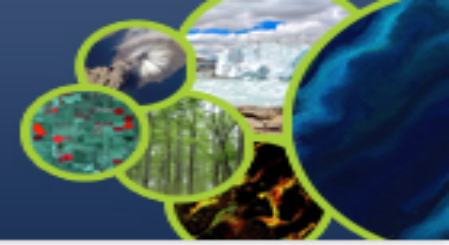


Contains modified Copernicus Sentinel-1 data (2021), processed by AUTH

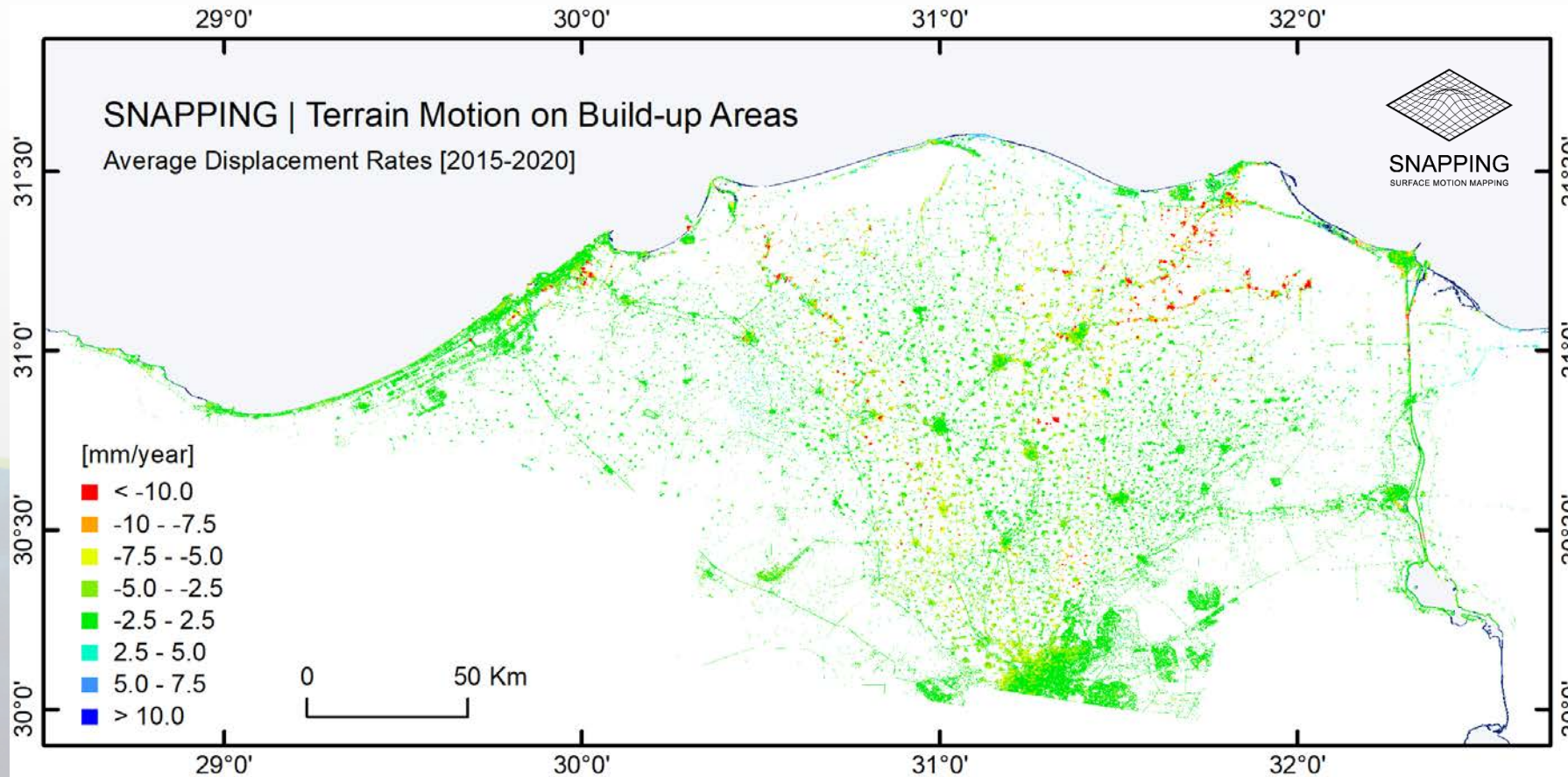


Photorealistic 3D model of a Kastelli fault segment, an active fault segment nearby the triggered tectonic structure. Morphological discontinuities (white arrows) along faults clearly indicate their activity during relatively recent geological era.

Vassilakis, E. et al. The 27 September 2021 Earthquake in Central Crete (Greece)—Detailed Analysis of the Earthquake Sequence and Indications for Contemporary Arc-Parallel Extension to the Hellenic Arc. *Appl. Sci.* **2022**, *12*, 2815. <https://doi.org/10.3390/app12062815>



Build-up areas of the Nile Delta as outlined by the ESA WorldCover 2020 global product



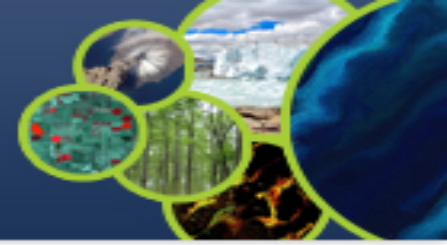
Project supported by ESA NoR sponsorship involving the National Authority for Remote Sensing & Space Sciences (**NARSS**) of Egypt, the Aristotle University of Thessaloniki (**AUTH**) in Greece and the French Geological Survey (**BRGM**)

Sentinel-1 Tracks:  
**Descending 065 & 167**  
Observation Period:  
**2015-2020 (~6 years)**  
Nu of Sentinel-1 Scenes:  
**517**  
Nu of PS points:  
**~516k**

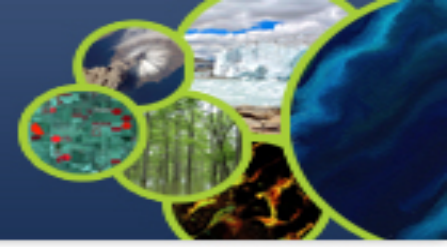
Contains modified Copernicus Sentinel-1 data (2015-2020), processed on GEP by NARSS/AUTH







- Co-located data & processing still the best approach to ensure wider usage of EO data; yet it is challenging (e.g. improve multi-sourcing as storage cost affects data availability)
- Improve parallelization & scalability of EO services
- Build chains that utilize other EO missions (than Copernicus Sentinel)
- Connecting GEP to other processing environments, e.g. work started to federate GEP with WASDI to address hydro-met hazards
- Integrate EO services to address exposure & vulnerability
- Look beyond EO data to include non-EO information layers and in-situ measurements



# Thank you

## **Geohazards Lab:**

Fabrizio Pacini (Terradue) [fabrizio.pacini@terradue.com](mailto:fabrizio.pacini@terradue.com)

Michael Foumelis (AUTH) [mfoumelis@geo.auth.gr](mailto:mfoumelis@geo.auth.gr)

Jean-Philippe Malet (CNRS/EOST) [jeanphilippe.malet@unistra.fr](mailto:jeanphilippe.malet@unistra.fr)

Philippe Bally (ESA) [philippe.bally@esa.int](mailto:philippe.bally@esa.int)