



PROGRAMME OF
THE EUROPEAN UNION



Validation Areas and Sites Description Document

SERVICES SUPPORTING THE EUROPEAN
ENVIRONMENT AGENCY'S (EEA)
IMPLEMENTATION OF THE COPERNICUS
EUROPEAN GROUND MOTION SERVICE –
PRODUCT VALIDATION.



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1. INTRODUCTION

This document is part the documentation connected to the European Ground Motion Service (EGMS) products validation as specified in the framework contract EEA/DIS/R0/21/009. The validation of the Interferometric Synthetic Aperture Radar open datasets at continental scale has the following goals and considerations:

- It verifies the **usability** of the data for different applications according to initial user requirements and with respect to the fields of application foreseen by the Validation of the EGMS Product Portfolio¹ and the EGMS End User Requirement² documents.
- It determines if the **quality** of the products is consistent with the technical specifications for different areas and applications. It is used to confirm the conclusions of the EGMS Quality Assurance and Control Reports.
- It addresses the **completeness** and **consistency** of the data products together with their **accuracy**.
- It is performed **independently** from the EGMS production. The validation datasets used, and the chosen procedures/criteria are documented in deliverables D3.1, D5 and D6.1.
- It is based on the comparison of data of different nature. Therefore, a complete agreement is most likely impossible, and differences may not be related to a quality issue.

In the following sections, the validation areas characteristics, EGMS coverage and target phenomena are described and accompanied by descriptive figures and maps.

¹ <https://land.copernicus.eu/user-corner/technical-library/egms-end-user-requirements-document>

² <https://land.copernicus.eu/user-corner/technical-library/validation-approach-of-the-egms-product-portfolio>

2. VALIDATION AREAS AND SITES

The following map presents a global overview of the approximative site location for each of the validation activities (Figure 1). The same overview can be consulted in a tabular format (Table 1) linking validation activity, site and data provider.

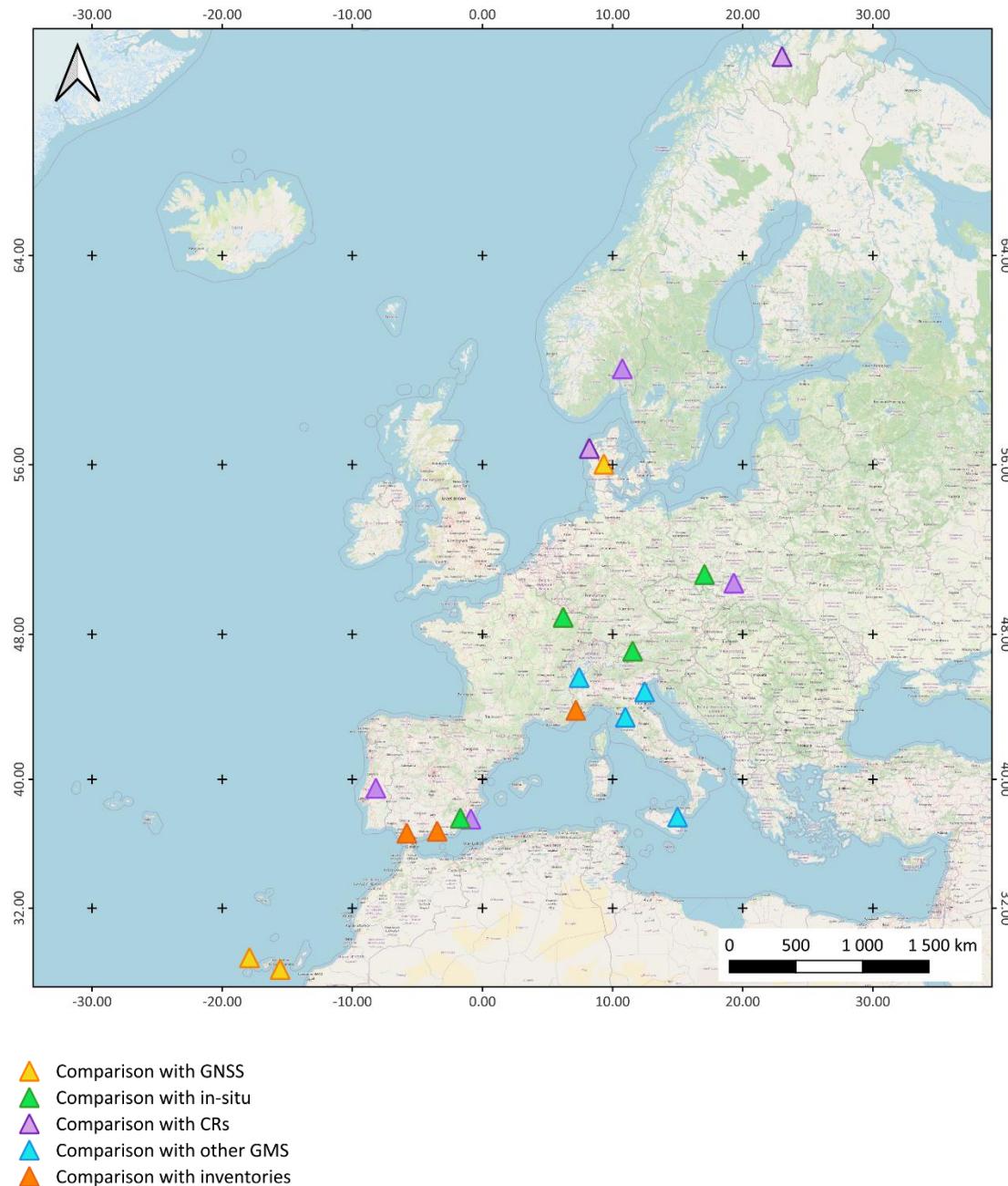


Figure 1: Validation Activities (VA) and their validation sites (approximative).

Table 1: Summary of Validation sites grouped by Validation Activity

Validation Activity	Validation site ID - description	Data Provider
Point density check	VA1_1 – Urban area of Bologna, Italy	CLC Urban Atlas (EEA)
Point density check	VA1_2 – Urban area of Bucharest, Romania	CLC Urban Atlas (EEA)
Point density check	VA1_3 – Urban area of Stockholm, Sweden	CLC Urban Atlas (EEA)
Point density check	VA1_4 – Urban area of Barcelona, Spain	CLC Urban Atlas (EEA)
Point density check	VA1_5 – Urban area of Sofia, Bulgaria	CLC Urban Atlas (EEA)
Point density check	VA1_6 – Urban area of Warsaw, Poland	CLC Urban Atlas (EEA)
Point density check	VA1_7 – Urban area of Bratislava, Slovakia	CLC Urban Atlas (EEA)
Point density check	VA1_8 – Urban area of Brussels, Belgium	CLC Urban Atlas (EEA)
Point density check	VA1_9 – Rural area of Bolzano, Italy	CLC Urban Atlas (EEA)
Point density check	VA1_10 – Rural area of Las Palmas, Spain	CLC Urban Atlas (EEA)
Point density check	VA1_11 – Rural area Zilina, Slovakia	CLC Urban Atlas (EEA)
Point density check	VA1_12 – Rural area Tromso, Norway	CLC Urban Atlas (EEA)
Comparison with other GMS	VA2_1 – Mount Etna, Sicily Island, Italy	CNR/IREA
Comparison with other GMS	VA2_2 – Danish GMS, Thyborøn	DTU
Comparison with other GMS	VA2_4 – Valle d'Aosta/Italy GMS, Alps	Regional GMS
Comparison with other GMS	VA2_5 – Veneto/Italy GMS, Po delta	Regional GMS
Comparison with other GMS	VA2_6 – Tuscany/Italy GMS, north Apennines	Regional GMS
Comparison with Inventories of Phenomena	VA3_1 – National inventory (France)	BRGM
Comparison with Inventories of Phenomena	VA3_2 – Rules reservoir (Spain)	CSIC / IGME
Comparison with Inventories of Phenomena	VA3_3 – Post-mining area in Lorraine, France	BRGM
Comparison with Inventories of Phenomena	VA3_4 – Arcos de la Frontera, Spain	CSIC / IGME
Consistency check with Ancillary geo-information	VA4_1 – Municipal area of Oslo, Norway	NGI
Consistency check with Ancillary geo-information	VA4_2 – Cartagena-La Unión, Murcia (Spain)	CSIC / IGME
Consistency check with Ancillary geo-information	VA4_3 – Alto Guadalentín, Lorca, Spain	CSIC / IGME
Consistency check with Ancillary geo-information	VA4_4 – Silesia coal mine region, Czech Republic / Poland	CGS
Consistency check with Ancillary geo-information	VA4_5 – Lower Tagus Valley Fault System, Portugal	LNEG
Comparison with GNSS data	VA5_1 – Jutland, Denmark	DTU
Comparison with GNSS data	VA5_2 – Canary Islands, Spain	CNIG
Comparison with GNSS data	VA5_3 – Lorca, Spain	CNIG
Comparison with In-situ monitoring	VA6_1 – Lorca, Spain	CSIC / IGME
Comparison with In-situ monitoring	VA6_2 – Turow mine, Czech Republic / Poland	CGS
Comparison with In-situ monitoring	VA6_3 – Navis valley, Tyrol, Austria	GeoSphere
Comparison with In-situ monitoring	VA6_4 – Freyming-Merlebach, France	BRGM
Evaluation XYZ and displacements with ACR	VA7_1 – Thyborøn, Denmark	Geopartner
Evaluation XYZ and displacements with ACR	VA7_2 – Norway, various sites	NVE / NGU
Evaluation XYZ and displacements with ACR	VA7_3 – Calern, France	IGN

2.1 Point Density Check

For the VA1 sites Copernicus Urban Atlas data has been used (2018 release). Cartography is based on satellite images Interpretation (Pleiades, KOMPSAT, Planet, SPOT6, Super View, etc. - resolution 2 or 4 meters) and use of ancillary data (Google Earth, OpenStreetMap). The common legend for all VA1 datasets taken from Copernicus Land and used in the validation notebooks for consistency:

-
- 11100 11100: Continuous Urban fabric (S.L. > 80%)
 - 11210 11210: Discontinuous Dense Urban Fabric (S.L.: 50% - 80%)
 - 11220 11220: Discontinuous Medium Density Urban Fabric (S.L.: 30% - 50%)
 - 11230 11230: Discontinuous Low Density Urban Fabric (S.L.: 10% - 30%)
 - 11240 11240: Discontinuous very low density urban fabric (S.L. < 10%)
 - 11300 11300: Isolated Structures
 - 12100 12100: Industrial, commercial, public, military and private units
 - 12210 12210: Fast transit roads and associated land
 - 12220 12220: Other roads and associated land
 - 12230 12230: Railways and associated land
 - 12300 12300: Port areas
 - 12400 12400: Airports
 - 13100 13100: Mineral extraction and dump sites
 - 13300 13300: Construction sites
 - 13400 13400: Land without current use
 - 14100 14100: Green urban areas
 - 14200 14200: Sports and leisure facilities
 - 21000 21000: Arable land (annual crops)
 - 22000 22000: Permanent crops
 - 23000 23000: Pastures
 - 24000 24000: Complex and mixed cultivation patterns
 - 25000 25000: Orchards
 - 31000 31000: Forests
 - 32000 32000: Herbaceous vegetation associations
 - 33000 33000: Open spaces with little or no vegetations
 - 40000 40000: Wetlands
 - 50000 50000: Water

Figure 2: CLC legend (Copernicus Land).

For this validation activity, 12 sites have been selected (large areas combined with mountainous areas) with validated Urban Atlas data covering the different algorithms used to produce the InSAR timeseries. The aim is to ensure that the point density is consistent across the EU territories.

Test site ID / Name

Eight different **urban** sites are proposed covering the different EGMS interferometric processing entities:

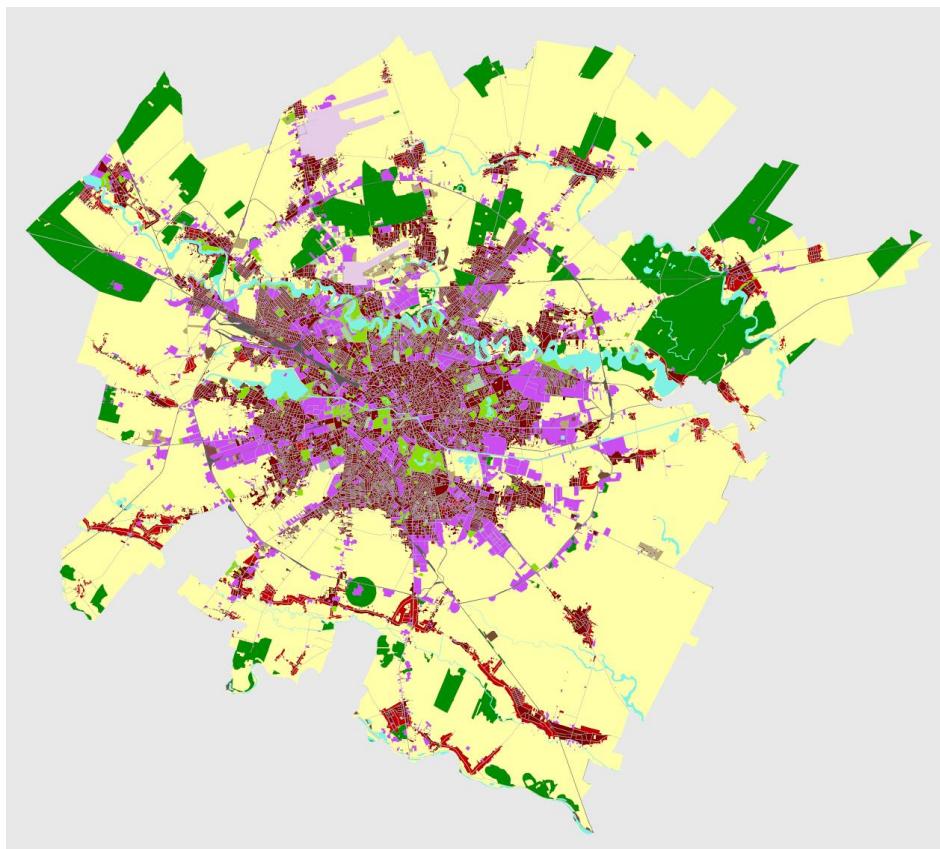
- VA1_1** – Urban area Bologna, Italy
- VA1_2** – Urban area Bucharest, Romania
- VA1_3** – Urban area Stockholm, Sweden
- VA1_4** – Urban area Barcelona, Spain
- VA1_5** – Urban area Sofia, Bulgaria
- VA1_6** – Urban area Warsaw, Poland
- VA1_7** – Urban area Bratislava, Slovakia
- VA1_8** – Urban area Brussels, Belgium

And four different **rural/mountainous** sites are proposed covering the different EGMS production team providers:

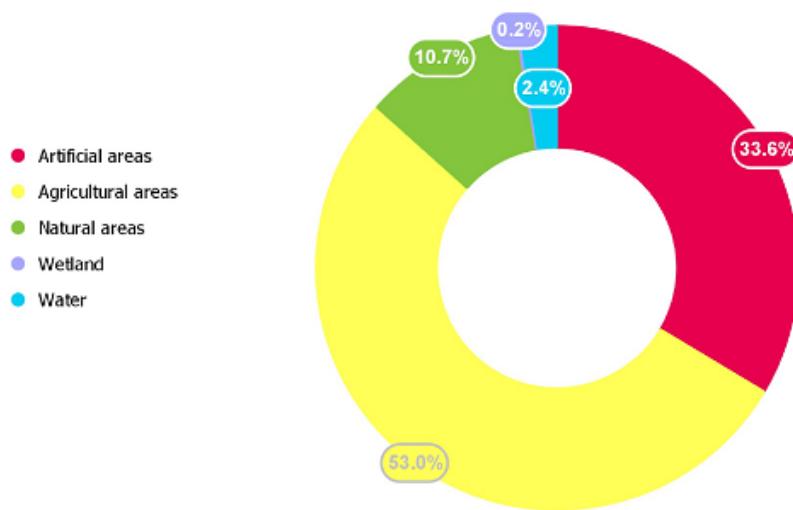
- VA1_9** – Rural area Bolzano, Alps, Italy
- VA1_10** – Rural area Las Palmas, Canary Islands, Spain
- VA1_11** – Rural area Zilina, Tatras, Slovakia
- VA1_12** – Rural area Tromso, Norway

Validation area characteristics

Urban atlas has generous buffers around the metropolitan area hotspots. That means all land cover classes are largely represented. For example the city of Bucharest (legend Figure 2):



With a spread representation of urban, agricultural, forest and water classes:

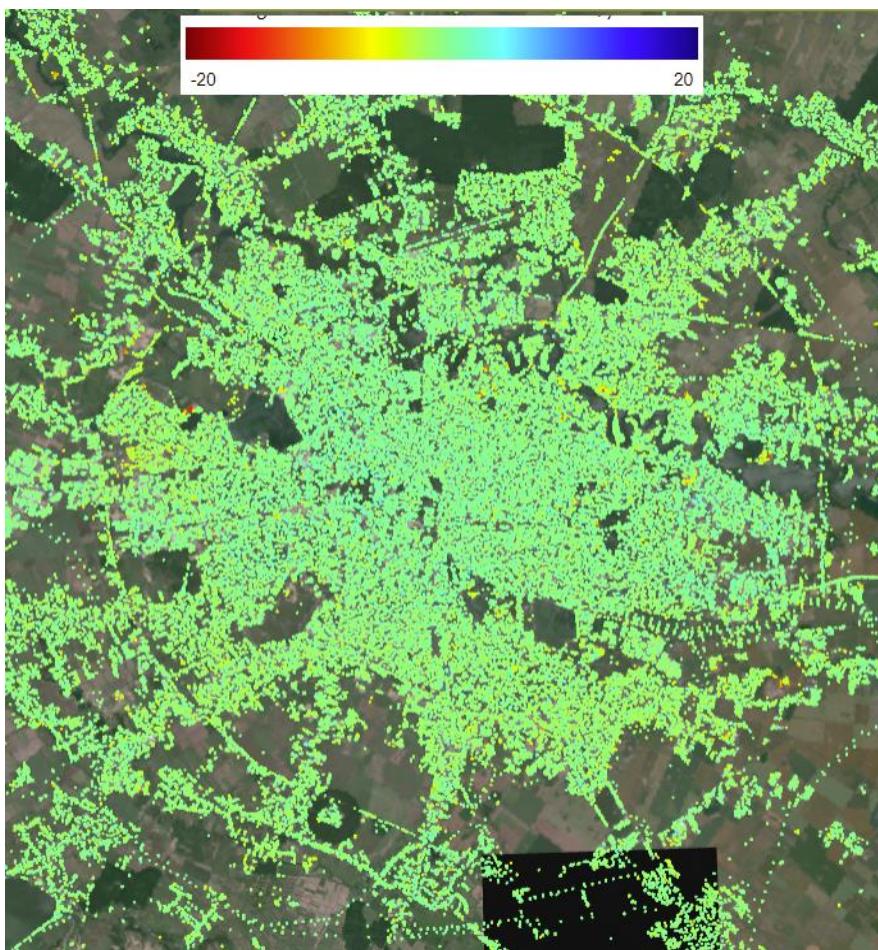


Validation area target phenomena

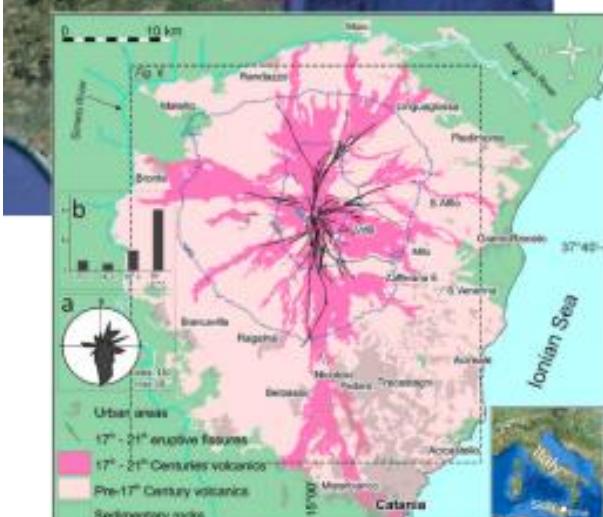
Only measurement point density is evaluated in this sites.

Validation area EGMS coverage

Coverage of Bucharest (Level 2A Descending) with high density in artificial surfaces.

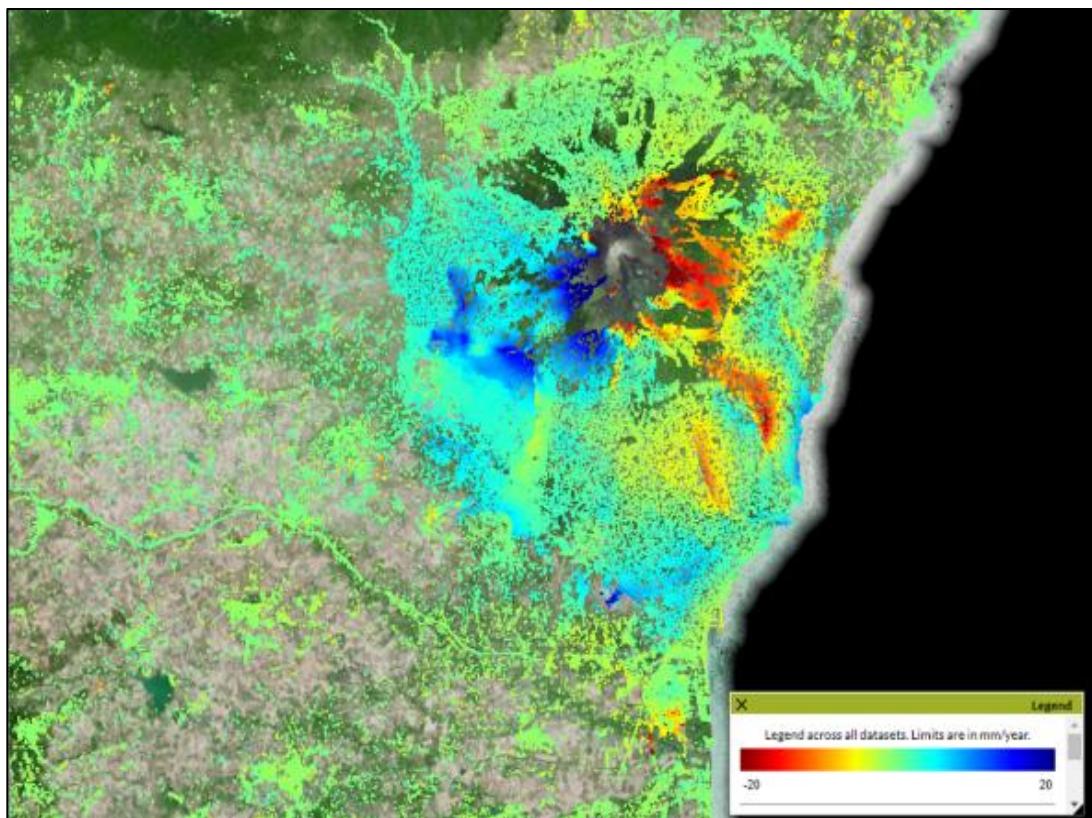


2.2 Comparison with other ground motion services

Test site ID / Name
VA2_1 – Mount Etna, Sicily Island, Italy
Validation area characteristics
Mount Etna, with its height of about 3,300 m, is the largest active onshore volcano in Europe. The volcanic activity is characterized by summit eruptions from five craters, and by fissural eruptions mainly clustered along three rift zones extending from the summit toward northeast, south, and west, respectively (Cappello et al., 2013). This area of interest is, moreover, characterized by a sliding into the Ionian Sea at rates of centimetres per year, magma pressure, eruptive activity, dyke intrusions, basement uplift, etc. Therefore, the IREA-CNR team considers the Etna volcano particularly suitable for the EGMS validation activities.
  Figure: Capello et al (2013)
Validation Area target phenomena
Particularly relevant are the abrupt surface deformation phenomena caused by the 24–27 December 2018 Mount Etna eruption occurred from fissures located on the volcano eastern flank and accompanied by a seismic swarm, which culminated on 26 December with a strong seismic event (ML 4.8) along the Fiandaca Fault. Moreover, very relevant are also the intense long-term ground deformations affecting the volcano, as its eastern sliding flank into the Ionian Sea, and those characterizing the fault systems that have cropped out the Etna volcano. In particular, the Pernicana–Provenzana Fault System is remarked, which is the northern boundary of the eastern sliding flank, as well as the southern boundary identified by several faults (Fiandaca, Trecastagni, Tremestieri Faults).

Validation Area EGMS coverage

The Mount Etna area of interest is fully covered by the EGMS Level 3 products:



Test site ID / Name

VA2_2 – Danish GMS

Validation area characteristics

The validation site for the Danish GMS is located at the fishing town of Thyborøn at the west coast of Denmark. It is located on a sandy barrier towards the North Sea and is vulnerable to floods from the adjacent Limfjord due to its low elevation (1.0-2.5m).

The older parts of Thyborøn are in the southwest and north. Before being developed on sandy landfill since the 1950s, the central and eastern parts were composed of marshland and fjord bottom. A harbor expansion has recently been developed on a new landfill.



References:

Andersen, T.B., 2018. *Overview of the geological conditions in the Thyborøn model area*. GeoAtlas Live Documentation Report 1, 2018-07-12

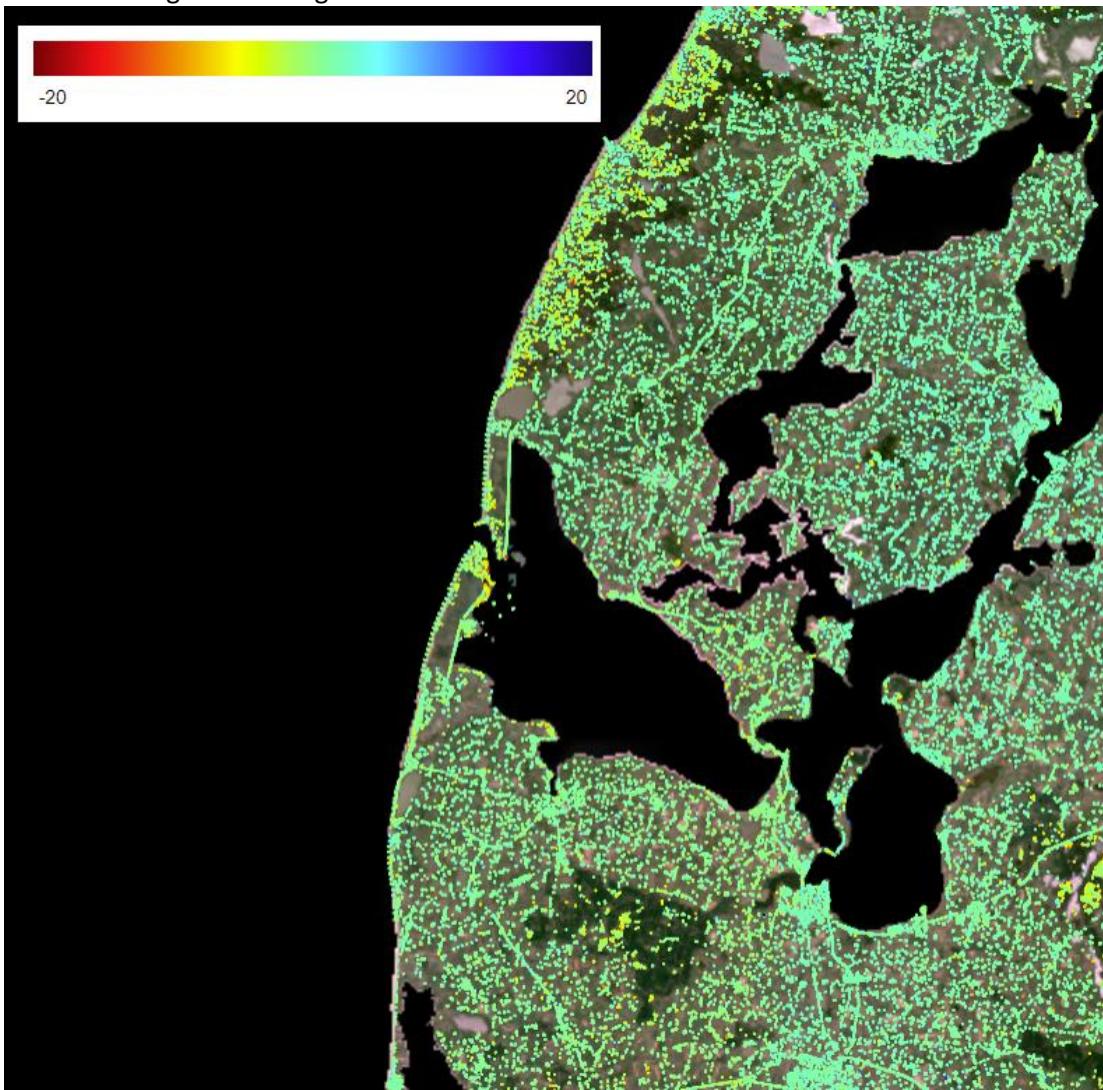
Sørensen, C. S., Broge, N. H., Mølgaard, M. R., F. Levinsen, J., Okkels, N., & Knudsen, P., 2016. *Advancing Coastal Climate Adaptation in Denmark by Land Subsidence Mapping using Sentinel-1 Satellite Imagery*. Geoforum Perspektiv, 15(28), 46-59.

Validation Area target phenomena

Subsidence of varying degree towards the Limfjord site of Thyborøn. The observed subsidence is believed to result from the overall sedimentary structure of the barriers and landfill including compression of certain layers.

Validation Area EGMS coverage

EGMS shows good coverage of the area. Some tracks do not cover the second half of 2015.



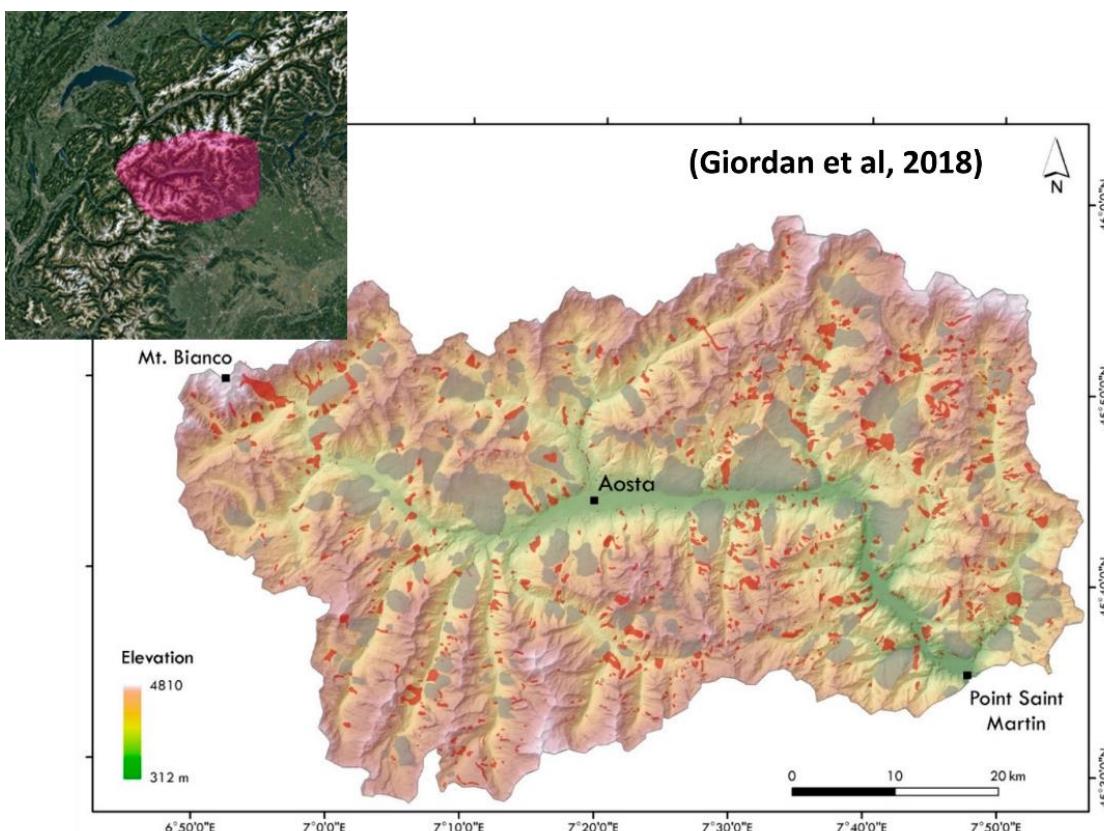
Test site ID / Name

VA2_4 – Valle d'Aosta/Italy GMS

Validation area characteristics

The Aosta Valley (Valle d'Aosta in Italian) is a small region (3200 km^2), located in an alpine mountainous territory in northwestern Italy with large variations in elevation from 312 m (Pont Saint Martin) to 4810 m a.s.l. (Monte Bianco peak) and more than half of its territory above 2000 m a.s.l. (Giordan et al, 2018).

Consequently, the steep topography with high peaks and deep valleys is prone to landslides.



References:

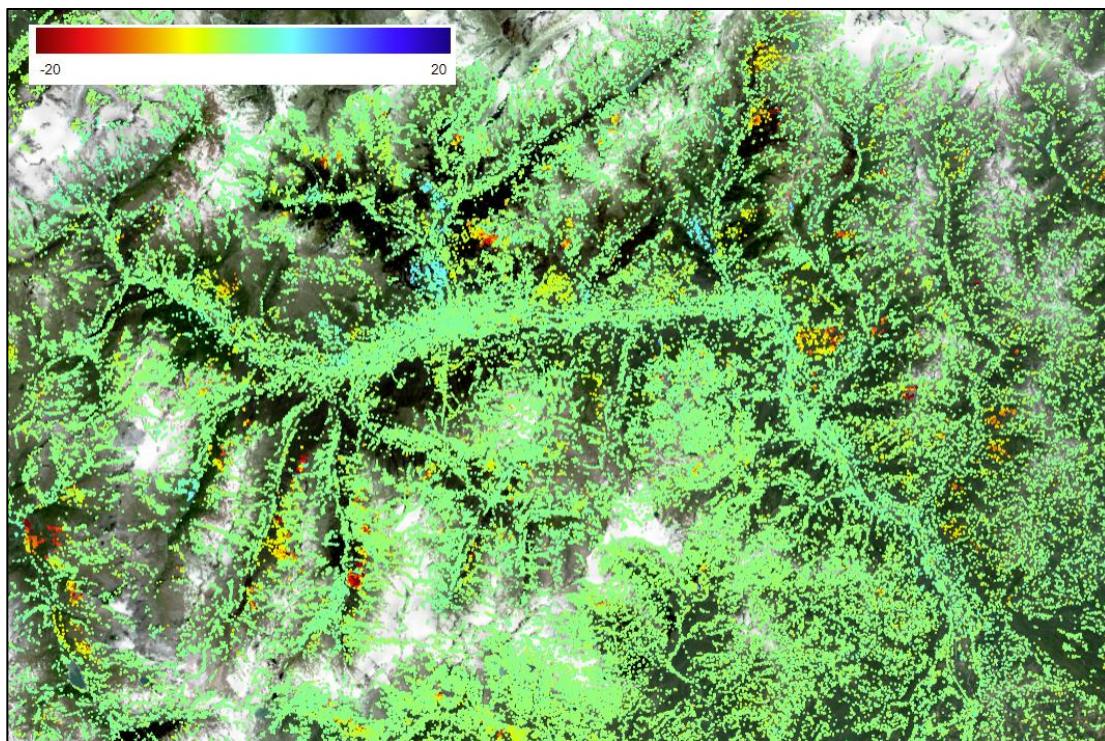
Giordan, D., Cignetti, M., Wrzesniak, A., Allasia, P., Bertolo, D., 2018. *Operative Monographies: Development of a New Tool for the Effective Management of Landslide Risks*. Geosciences (Switzerland). 8. 485. 10.3390/geosciences8120485.

Validation Area target phenomena

Giordan et al., 2018, estimated that more than 17% of this the region of Vale d'Aosta is affected by gravitational phenomena and which includes shallow landslides (e.g., debris flow, planar and rotational slide), rock fall, and large slope instabilities and Deep-seated Gravitational Slope Deformations.

Validation Area EGMS coverage

Coverage partially limited due to vegetation, snow cover and steep topography at landslide sites.



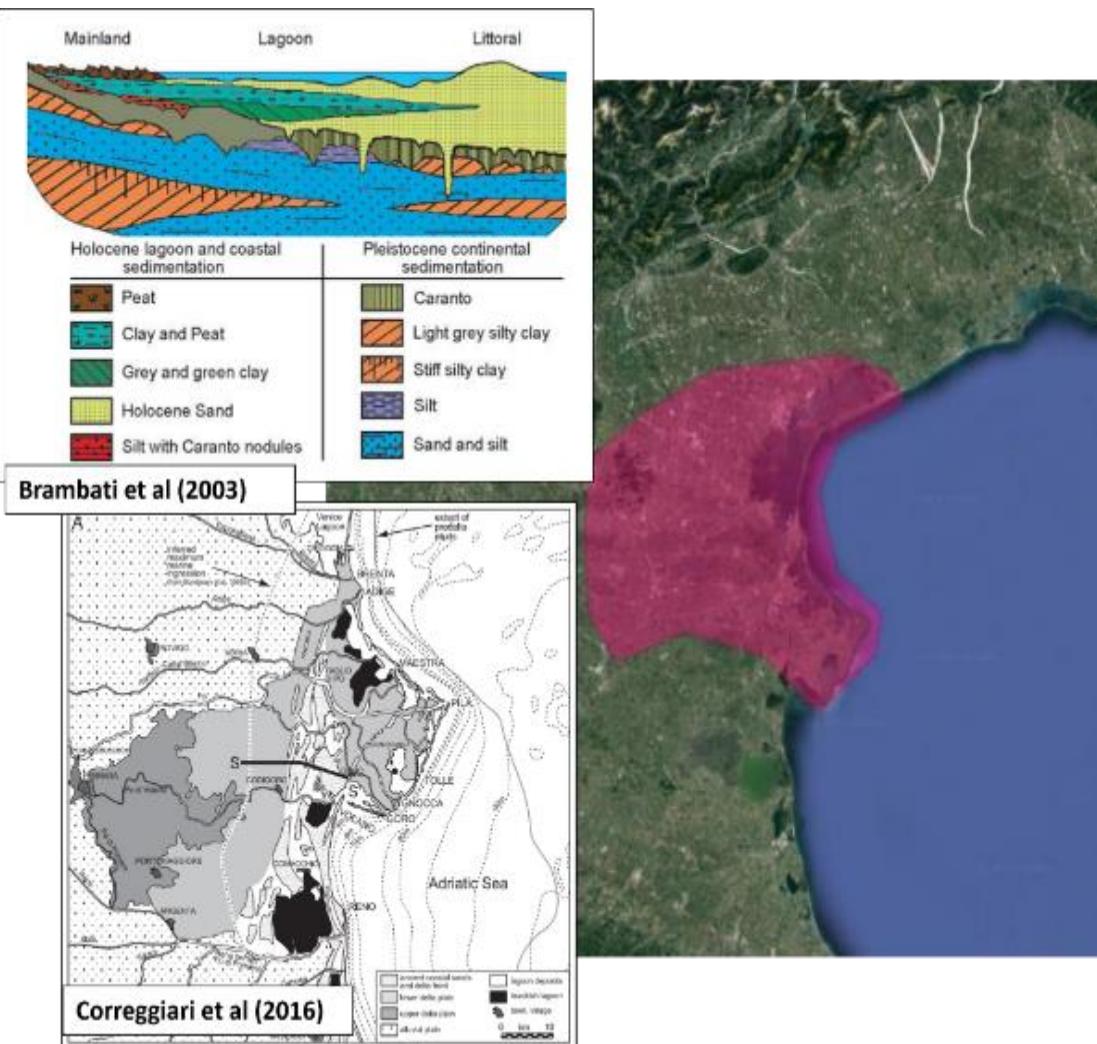
Test site ID / Name

VA2_5 – Veneto/Italy GMS

Validation area characteristics

The Venice lagoon area has been affected by subsidence for a long time. Combined with sea-level rise and the small elevation of the city of Venice, this causes many problems, especially as it compromises the safety of many historic heritage sites. The lagoon area is of considerable size with an area of about 50 km x 10 km. In order to protect the city and its lagoon environment from increased flooding, the multi-billion Euro MOSE project started construction on the early 2000s.

Another area of interest in this region is the Po River delta, a complex ecosystem with an extension of approx. 400km². It is the result of sedimentary processes linked to human activity.



References:

Fabris, M., Battaglia, M., Chen, X., Menin, A., Monego, M., Floris, M., 2022. An Integrated InSAR and GNSS Approach to Monitor Land Subsidence in the Po River Delta (Italy). *Remote Sensing*. 14. 5578. 10.3390/rs14215578.

Brambati, A., Carbognin, L., Quaia, T., Teatini, P., Tosi, L., 2003. *The Lagoon of Venice: Geological setting, evolution and land subsidence*. Episodes. 26. 10.18814/epiugs/2003/v26i3/020.

Correggiari, A., Cattaneo, A., Trincardi, F., 2005. Depositional Patterns in the Late Holocene Po Delta System. 10.2110/pec.05.83.0365.

Validation Area target phenomena

The Venice lagoon area has been affected by subsidence for a long time. Historic subsidence rates were estimated ranging from 0.6 to 1.6 mm/year, however, in the past century a total loss of elevation of 25 cm is estimated, of which 15 cm is attributed to ground water pumping and 10 cm to sea level rise.

The subsidence in the Po River delta area is due to natural and anthropogenic causes (Fabris et al., 2022). The natural component is mostly connected to the compressible Holocene deposits and amounts to 2-4mm/year. The anthropogenic component is connected to the exploitation of water aquifers and can reach subsidence rate of from tens to hundreds of mm/year (Fabris et al., 2022).

Validation Area EGMS coverage

Generally good coverage in EGMS.



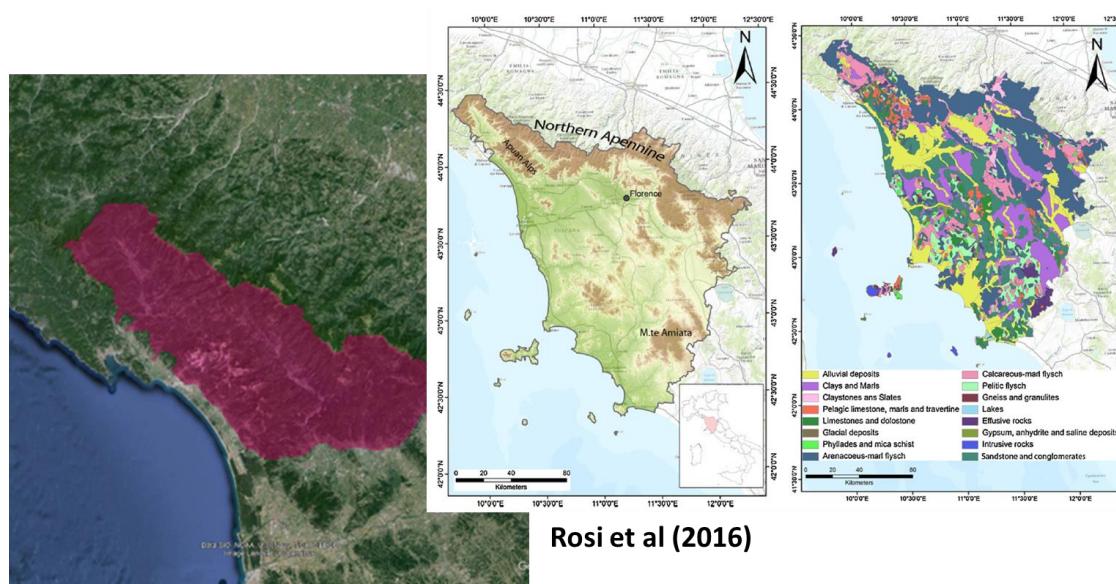
Test site ID / Name

VA2_6 – Tuscany/Italy GMS

Validation area characteristics

The validation site in the Tuscany Region covers the provinces of Massa Carrara, Lucca and Pistoia. The area is characterized by a large variety of landscapes, with coastal plains and hilly areas, as well as the mountainous areas covered by the Apennine ridge, which was formed by the collision of the European and African continental margins and reaches heights of up to about 2000 m a.s.l.

As the phenomena of interest for this validation site are landslides, flat planes, e.g. along the Mediterranean coast, have been excluded from the validation.



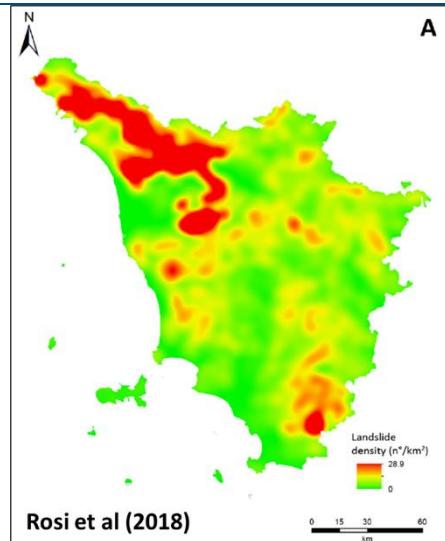
References:

- Rosi, A., Tofani, V., Agostini, A., Tanteri, L., Stefanelli, C.T., Catani, F., Casagli, N. (2016) Subsidence mapping at regional scale using persistent scatterers interferometry (PSI): The case of Tuscany region (Italy). International Journal of Applied Earth Observation and Geoinformation, 52 (2016), 328–337
- Rosi, A., Tofani, V., Tanteri, L., Tacconi Stefanelli, C., Agostini, A., Catani, F., Casagli, N. (2018) The new landslide inventory of Tuscany (Italy) updated with PS-InSAR: geomorphological features and landslide distribution. Landslides 15, 5-19. doi: 10.1007/s10346-017-0861-4
- Del Soldato, M., Solari, L., Poggi, F., Raspini, F., Tomás, R., Fanti, R., Casagli, N. (2019) Landslide-Induced Damage Probability Estimation Coupling InSAR and Field Survey Data by Fragility Curves. Remote Sensing 2019, 11(12), 1486; <https://doi.org/10.3390/rs11121486>

Validation Area target phenomena

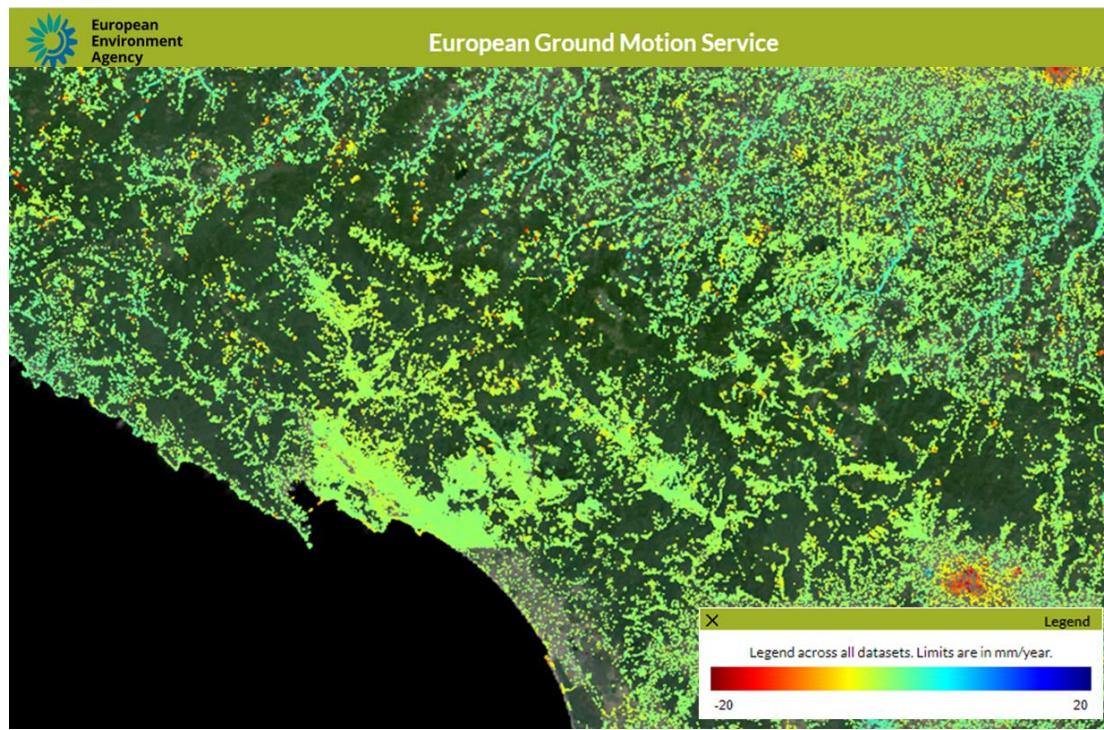
Worldwide, Italy is amongst the countries that are most affected by landslide activity. In the region of Tuscany, more than 100,000 landslide phenomena are known and mapped (Del Soldato et al., 2019), with the areas along the Apennine ridge showing the highest density in landslide activity (see Figure to the right by Rosi et al., 2018).

Both dormant and active landslides are present in the area, while for the purpose of comparing displacement measurements of two different InSAR datasets, only active landslides are relevant.

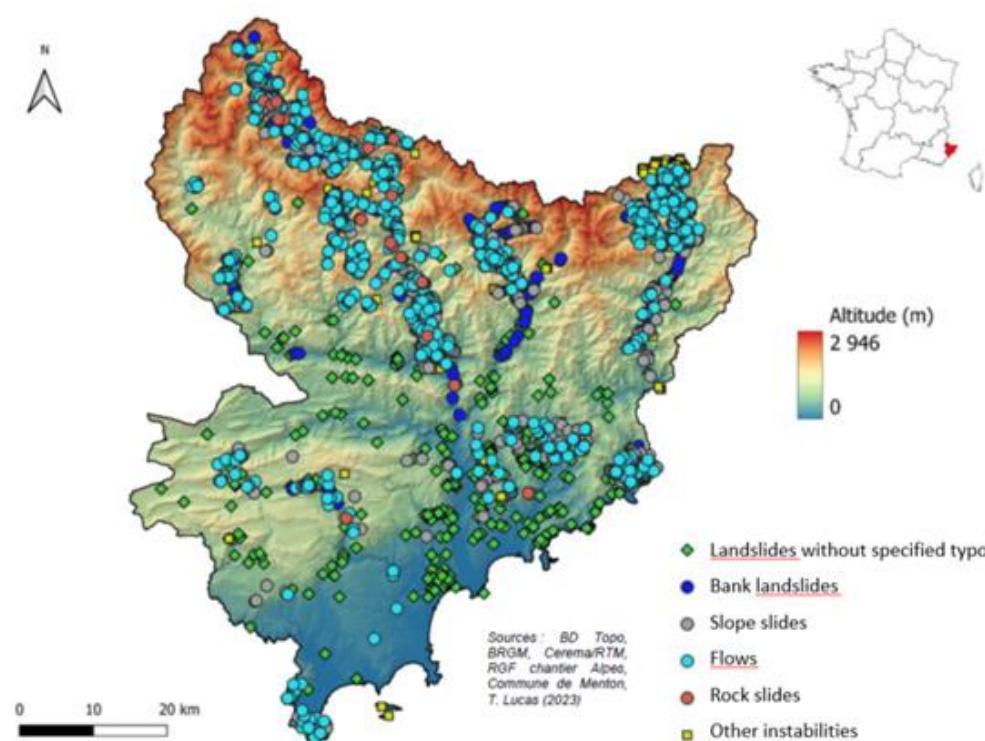


Validation Area EGMS coverage

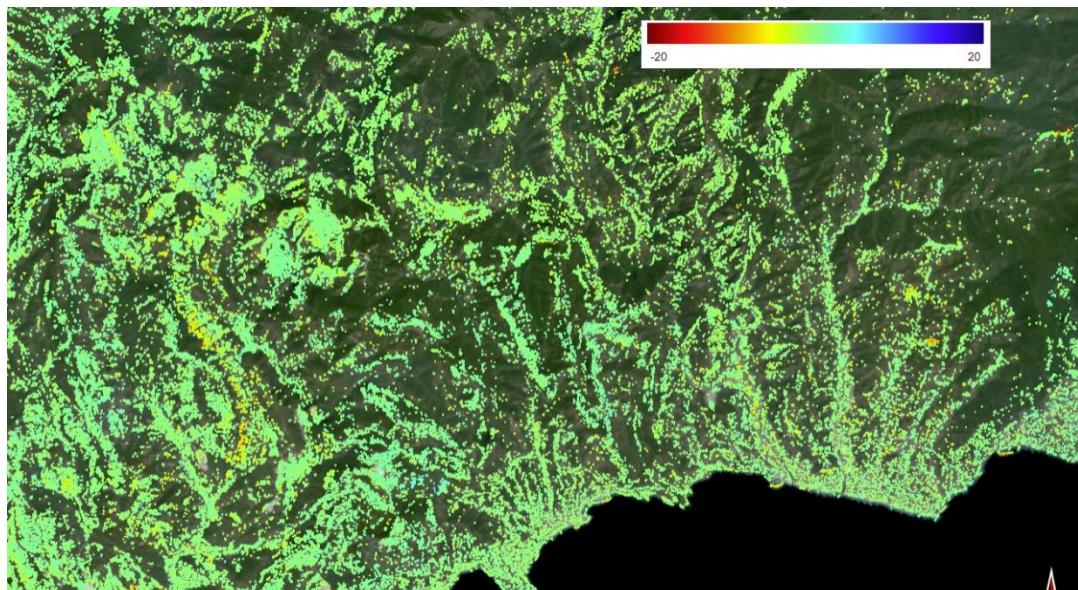
Coverage partially limited due to vegetation, especially in areas with stronger topography, including landslide locations.



2.3 Comparison with inventories of phenomena/events

Test site ID / Name
VA3_1 – National inventory (France)
Validation area characteristics
<p>The Land Motion database (BDMvt - available at https://www.georisques.fr) lists land motions recorded in mainland France and in the French West Indies, French Guiana and Reunion. The Alpes-Maritimes department is located in the Provence-Alpes-Côte d'Azur region of southeastern France, bordering Italy to the east. During 2023 the inventory on the department was improved by merging the BDMvt data with other sources (Lucas, 2023). This new inventory contains point data (locations of landslides) and polygons.</p>  <p><i>Landslides inventoried on Alpes-Maritimes (adapted from Lucas 2023)</i></p>
References :
<p>Théophile Lucas 2023. Proposition d'une carte de susceptibilité glissement de terrain sur le département des Alpes-Maritimes (06) dans le cadre de la réalisation d'un système de vigilance. Rapport de stage de Master GEE - GERINAT V1. BRGM, 8 p.</p>
Validation Area target phenomena
<p>The target phenomena are landslides. There are several areas where a large number of landslides have been recorded: the Tinée, Roya and Vésubie valleys, the area close to the Var, north of Nice and the municipality of Menton, with heavy urbanization on the slopes.</p>
Validation Area EGMS coverage

The area is covered by EGMS. As this is a mountainous area, density could be variable (and depending on ascending/descending modes)

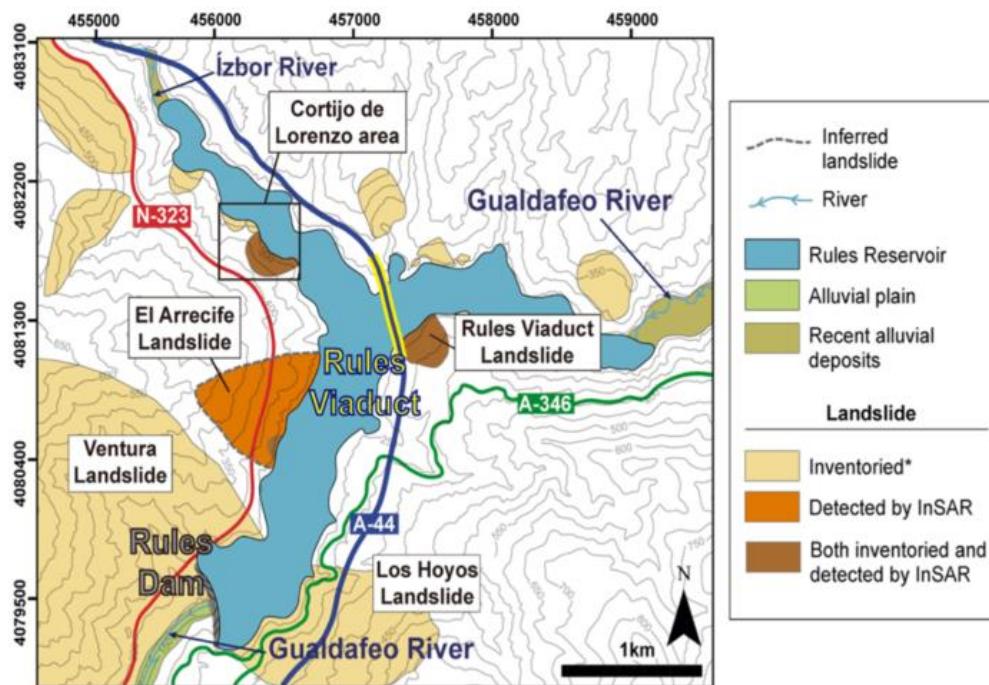


Test site ID / Name

VA3_2 – Local inventory – Rules Reservoir (Spain)

Validation area characteristics

Active landslides in the Rules Reservoir area (Southern Spain). The inventory is based on the integration of DInSAR results with a comprehensive geomorphological in order to determine the typology, evolution and triggering factors of three active landslides: Lorenzo-1, Rules Viaduct and El Arrecife.



Landslide inventory on Rules Reservoir Area (sources: Reyes-Carmona et al. 2020)

References:

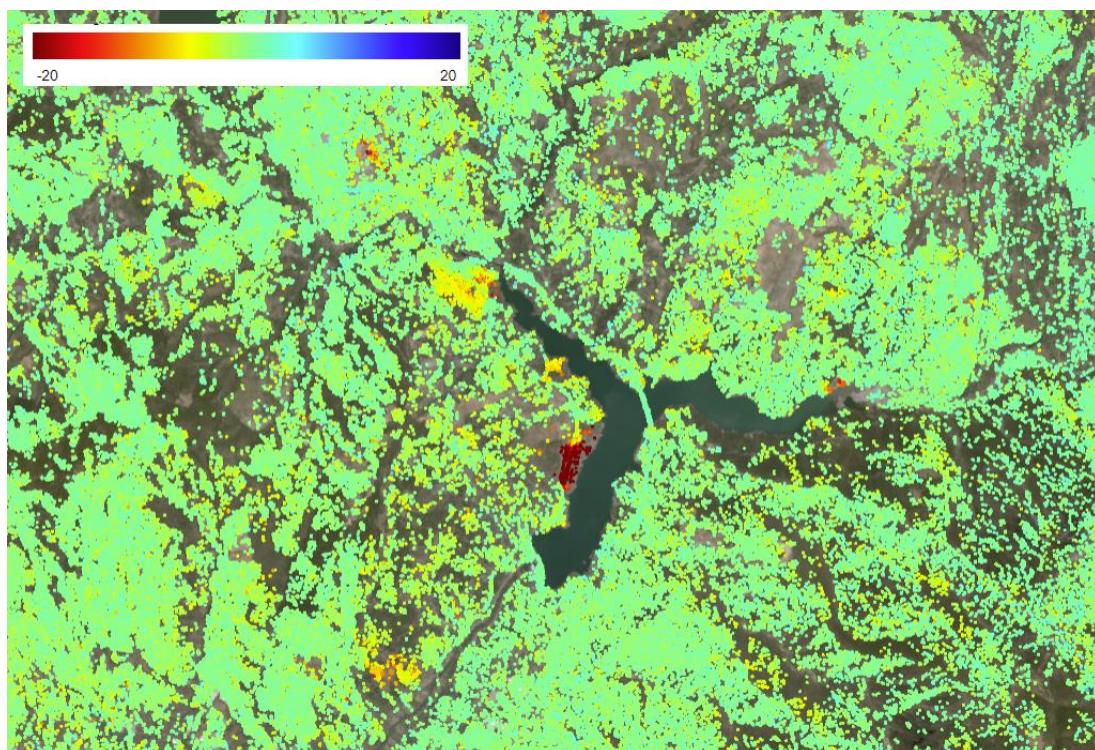
Reyes-Carmona et al. (2020) Sentinel-1 DInSAR for Monitoring Active Landslides in Critical Infrastructures: The Case of the Rules Reservoir (Southern Spain). *Remote Sens.* 2020, 12, 809

Validation Area target phenomena

The target phenomena are the landslides (identified in the inventory as polygons)

Validation Area EGMS coverage

The area is fully covered by EGMS.



Test site ID / Name

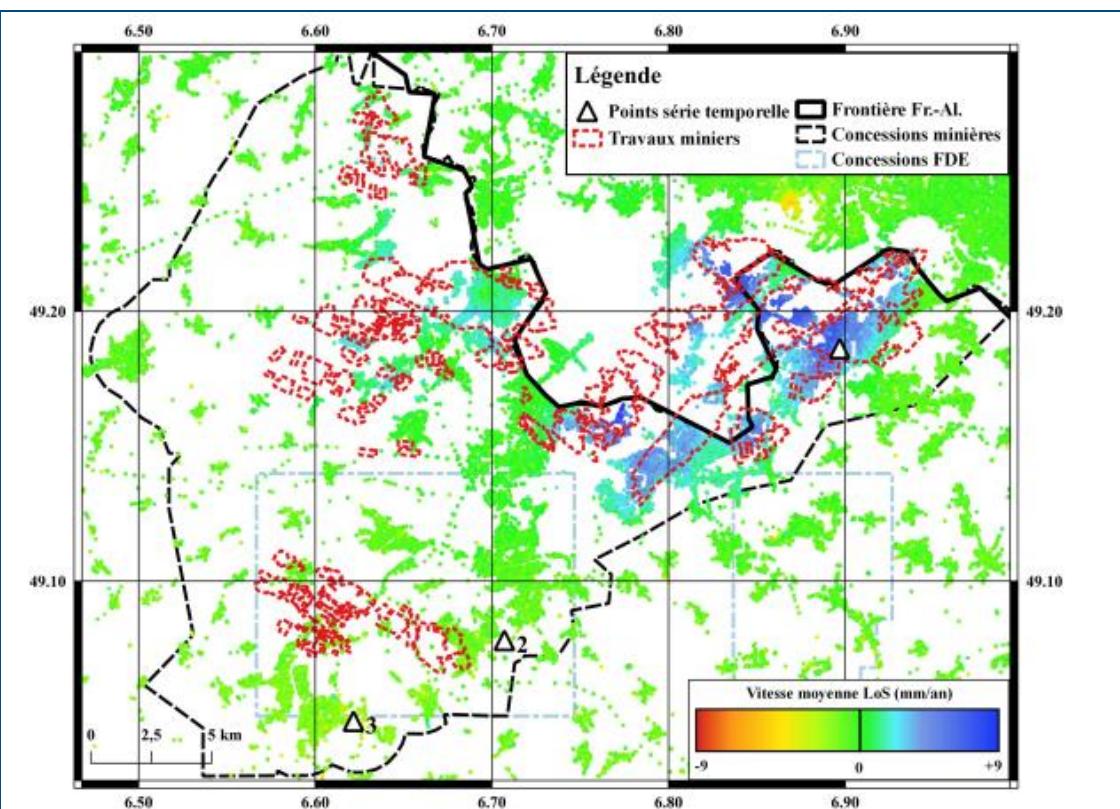
VA3_3 – Post-mining area in Lorraine, France

Validation area characteristics

The area is located in the Lorraine Region that includes municipalities like Forbach and Freyming-Merlebach, with abandoned coal mines that were active until 2004, covers an approximate area of around 50 square kilometers. This region was historically significant for coal mining, which played a vital role in its economy and development until the decline of the industry in the early 21st century.

Validation Area target phenomena

Motion due to post-mining (subsidence/uplift). Both subsidence and uplift are consequences of underground changes caused by mining, affecting the stability and usability of the land above. The site is monitored by levelling.



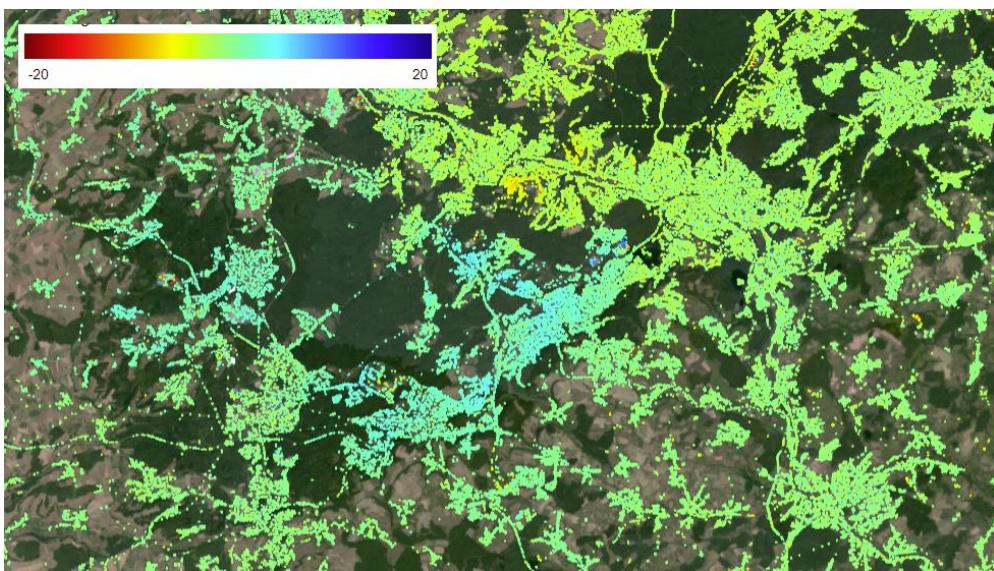
Validation area. Locations of past mining works are shown in red. Source: Modeste et al. 2022

References:

Guillaume M. et al.(2022), Déplacements de surface dans le bassin houiller lorrain : reflets des exploitations passées et actuelles. 11èmes journées nationales de géotechnique et de géologie de l'ingénieur, Institut National des Sciences Appliquées de Lyon [INSA Lyon], CFMS, CFMR, CFGI, Jun 2022, Lyon, France

Validation Area EGMS coverage

The area is covered by EGMS product levels 2A,2B,3.



Test site ID / Name

VA3_4 – Arcos de la Frontera, Spain

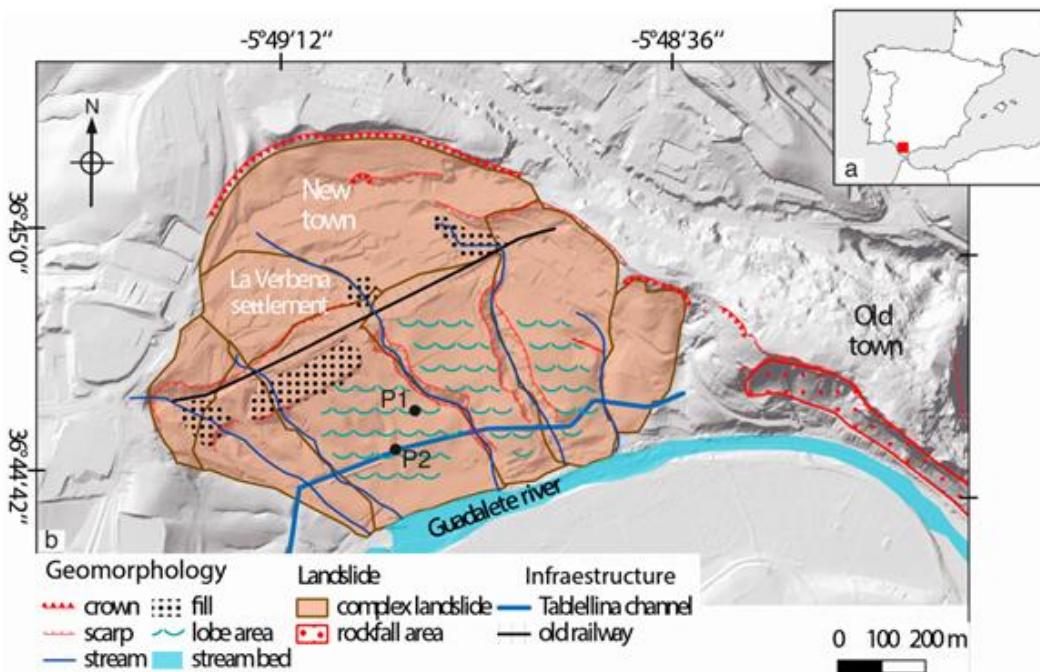
Validation area characteristics

The area is located in South Spain affected by a slow-moving landslide that has caused severe damage to buildings, forcing the evacuation of some of them. Database containing the detected slow-moving landslide About 20 km² around the landslide

Validation Area target phenomena

The validation has been focused on a landslide phenomenon

The Figure shows the entire extension of the complex landslide, composed of several coalescent bodies. The landslide is 925 m in length and 950 m in width. The terrain displaces mainly along a planar surface of rupture and the failure surface could be at an average depth of 10 m. Currently, the crown of the landslide is located in the contact boundary between the blue marls and the sandstones.

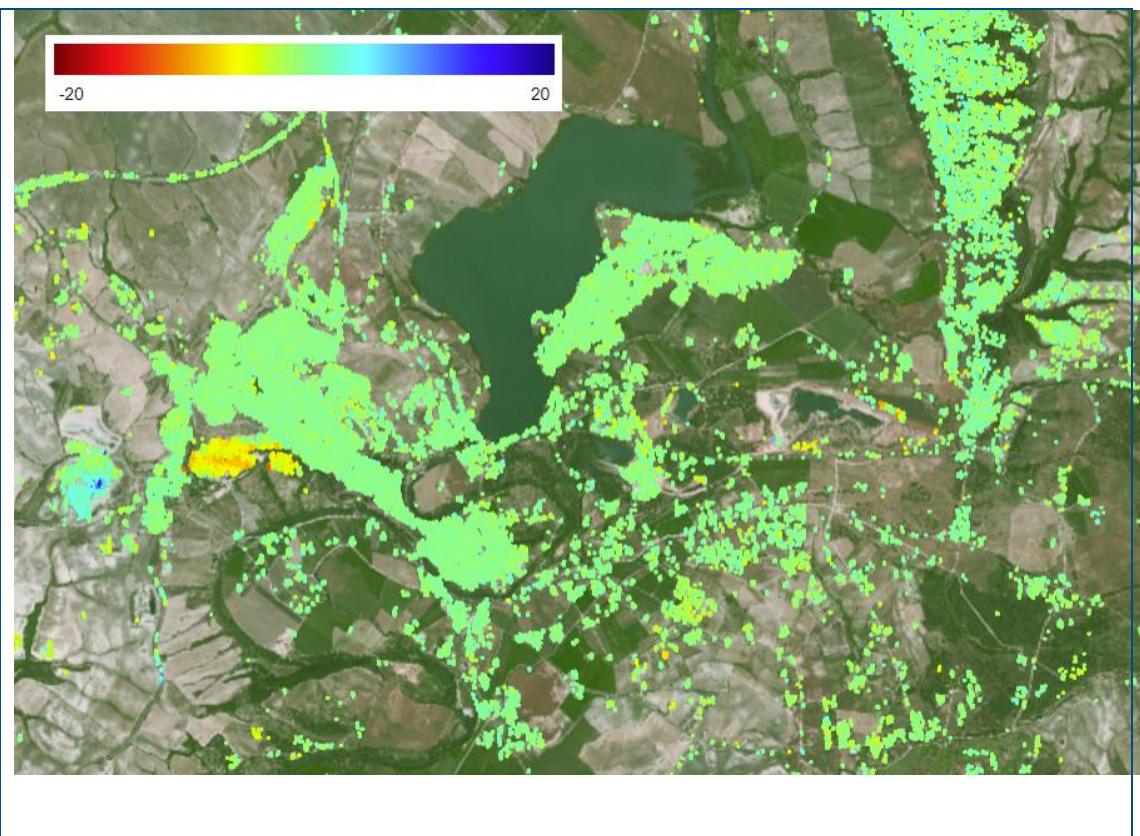


Reference:

Béjar-Pizarro M. et al. (2017), Mapping vulnerable urban areas affected by slow-moving landslides using Sentinel-1 InSAR data. Remote Sensing, 9(9), 876

Validation Area EGMS coverage

The area is covered by EGMS product levels calibrated/ortho as seen in the following figure:



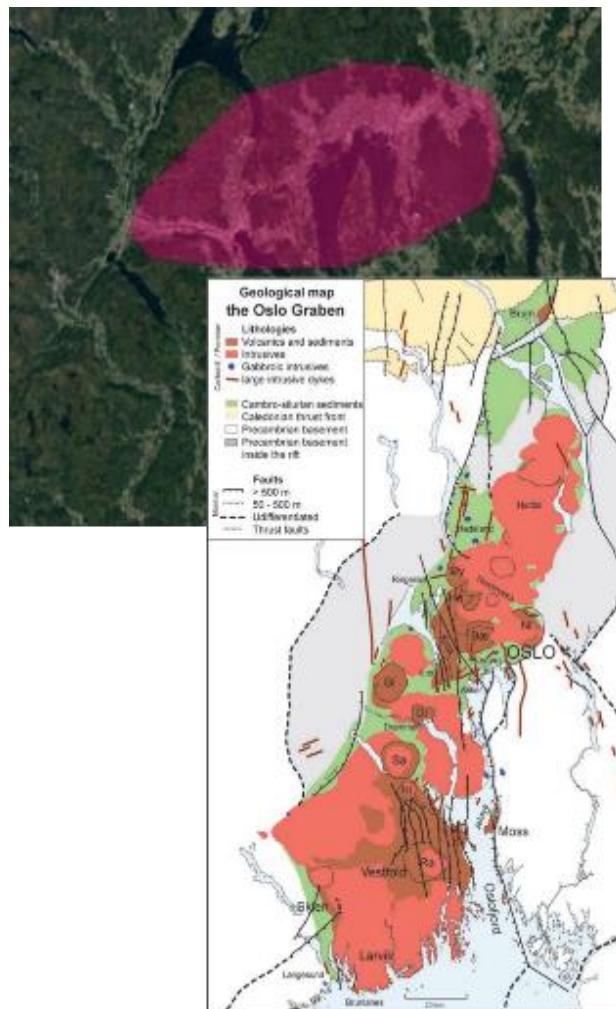
2.4 Consistency check with ancillary geo-information

Test site ID / Name

VA4_1 – Municipal area of Oslo, Norway

Validation area characteristics

The Oslo municipal area is located on an area of high geological and lithological variability. In addition, parts of the city ground were located below the sea surface after the last Ice age. This leads to a diversity of soils and bedrock below the city, some of which causing potential stability problems (e.g. clay, alum shale). In addition, at the outlet of Akerselva (the cities' main river), material from industry (e.g. saw dust, wooden "floats") have been deposited for several hundred years, to gain new land. These layers are especially vulnerable to e.g. pore-pressure changes.



References:

Larsen, B.T., Olaussen, S., Sundvoll, B., & Heeremans, M., 2008. *The Permo-Carboniferous Oslo Rift through Six Stages and 65 Million Years*. Episodes, 31, 52-58.

Hauser, C., Kalströhm, M., Karlsrud, K., Fosseide Boman, J.C., Guzman Sandoval, J., 2019. *Effects from extensive construction activities on pore pressure and settlements in central Oslo*. Proceedings of the XVII ECSMGE-2019. ISBN 978-9935-9436-1-3. https://www.ecsmge-2019.com/uploads/2/1/7/9/21790806/0259-ecsmge-2019_hauser.pdf

Validation Area target phenomena

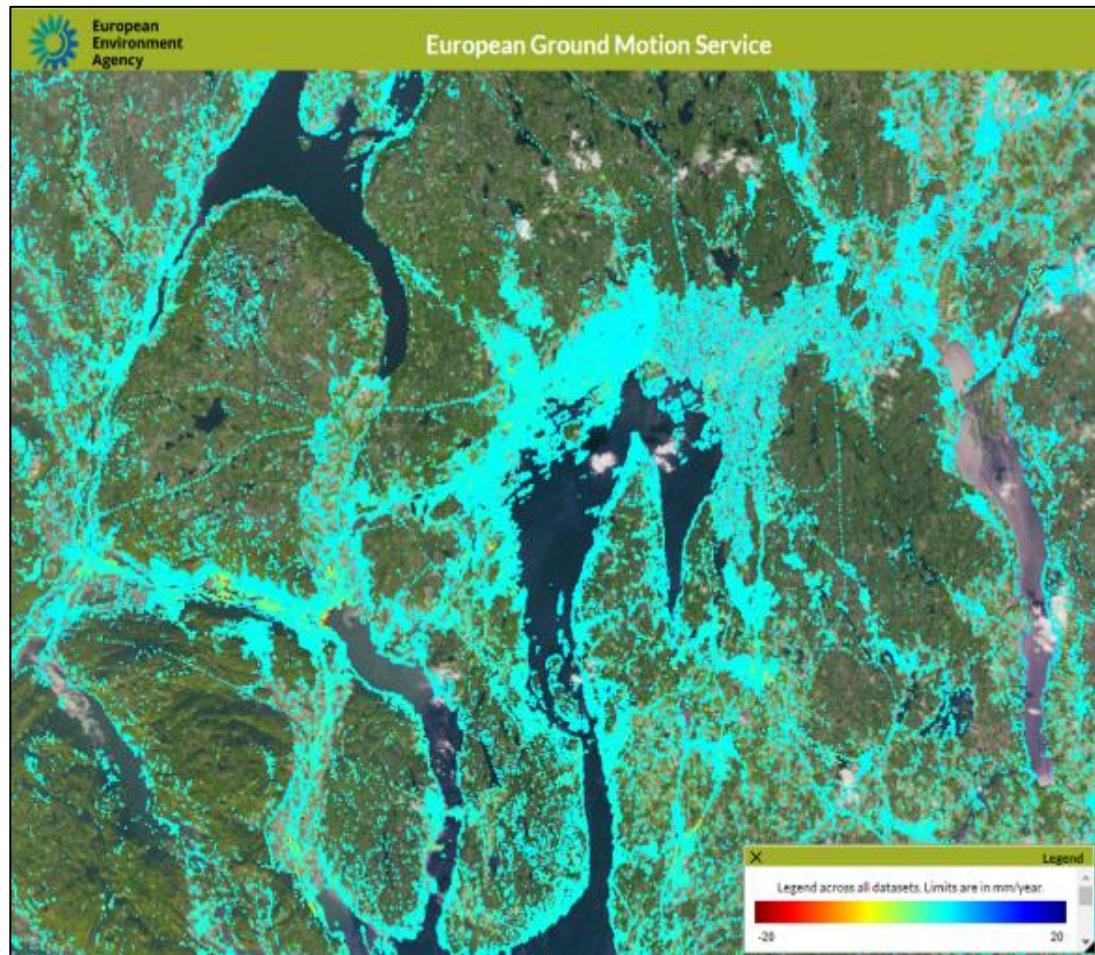
Urban subsidence: For the last 10 to 15 years, the area around the central station in Oslo has been subject to extensive building and infrastructure development. Construction activities have generated major settlements in the area, primarily caused by the reduction of pore pressure which is mainly due to leakage that occurred in connection with drilling activities.

References:

Hauser, C., Kalströhm, M., Karlsrud, K., Fosseide Boman, J.C., Guzman Sandoval, J., 2019. *Effects from extensive construction activities on pore pressure and settlements in central Oslo*. Proceedings of the XVII ECSMGE-2019. ISBN 978-9935-9436-1-3. https://www.ecsmge-2019.com/uploads/2/1/7/9/21790806/0259-ecsmge-2019_hauser.pdf

Validation Area EGMS coverage

The urbanised area shows good coverage by EGMS. As expected, adjacent forest areas and city parks show little to no measurement points.



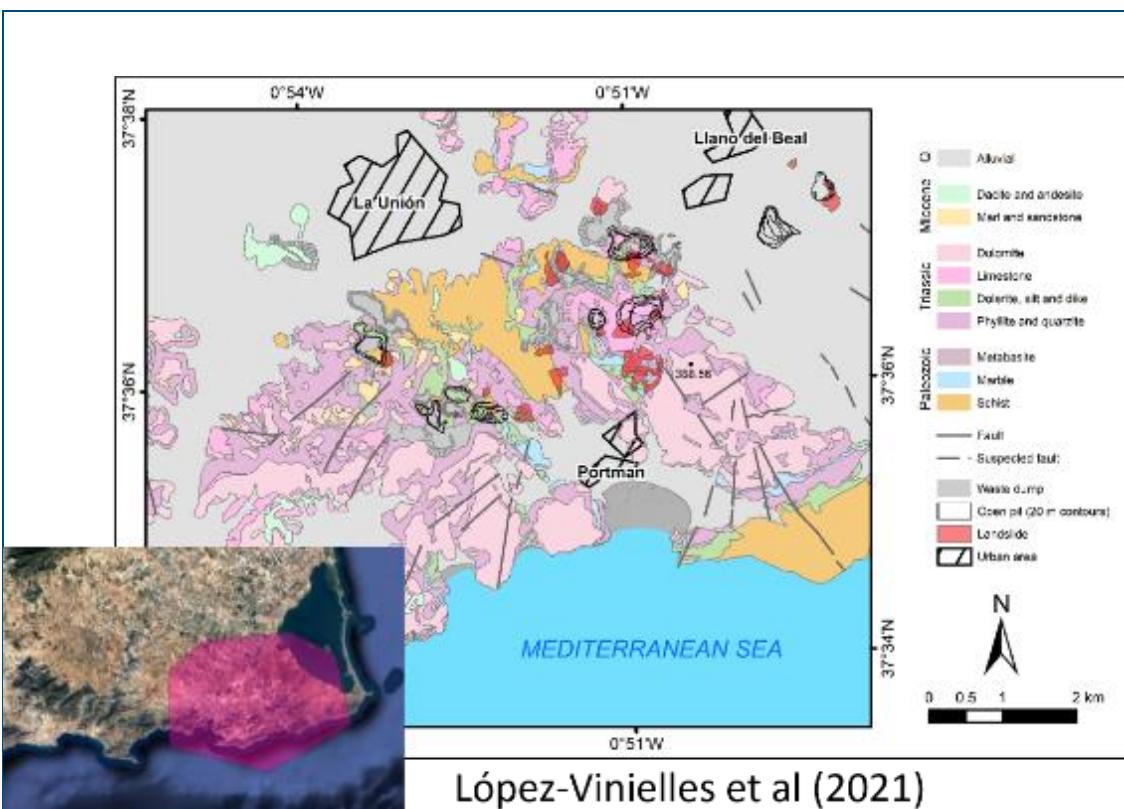
Test site ID / Name

VA4_2 – Cartagena-La Unión, Murcia (Spain)

Validation area characteristics

The La Union mining district is located in southeast Spain at the Mediterranean coast. The area has large Pb and Zn deposits and was exploited until 1992, mainly through underground mining until the 1960s, after which open-pit exploitation started.

Since 1956, the Brunita mine tailings were being stored in four stepped ponds at the watercourse of an NNO-SSE trending ravine. Subsequently, they were stored in a single, large pond. After the closure of the pond operations, certain work on dike stabilization was performed and debris from the Brunita mine started to accumulate. The mining works for > 50 years have led to the complete burial of the surrounding valleys and hills by mine waste material.



References:

López-Vinielles, J., Fernández-Merodo, J.A., Ezquerro, P., García-Davalillo, J.C., Sarro, R., Reyes-Carmona, C., Barra, A., Navarro, J.A., Krishnakumar, V., Alvioli, M., 2021. *Combining Satellite InSAR, Slope Units and Finite Element Modeling for Stability Analysis in Mining Waste Disposal Areas*. Remote Sens. 2021, 13, 2008. <https://doi.org/10.3390/rs13102008>

Martín-Crespo, T., Gómez-Ortiz, D., Martín-Velázquez, S., Martínez-Pagán, P., De Ignacio, C., Lillo, J., Faz., A., 2018. *Geoenvironmental characterization of unstable abandoned mine tailings combining geophysical and geochemical methods (Cartagena-La Union district, Spain)*, Engineering Geology, Volume 232, Pages 135-146, ISSN 0013-7952, <https://doi.org/10.1016/j.enggeo.2017.11.018>.

Validation Area target phenomena

The main deformation phenomena in the area are related to waste and tailing disposal facilities facing post mining slope instabilities. After mining was discontinued in 1992, various studies have shown that large amounts of toxic metals continue to be transferred with the spread of destabilized mining wastes to the nearby ecosystems. Most identified landslides directly affect waste dump areas and open-pit slopes.

References:

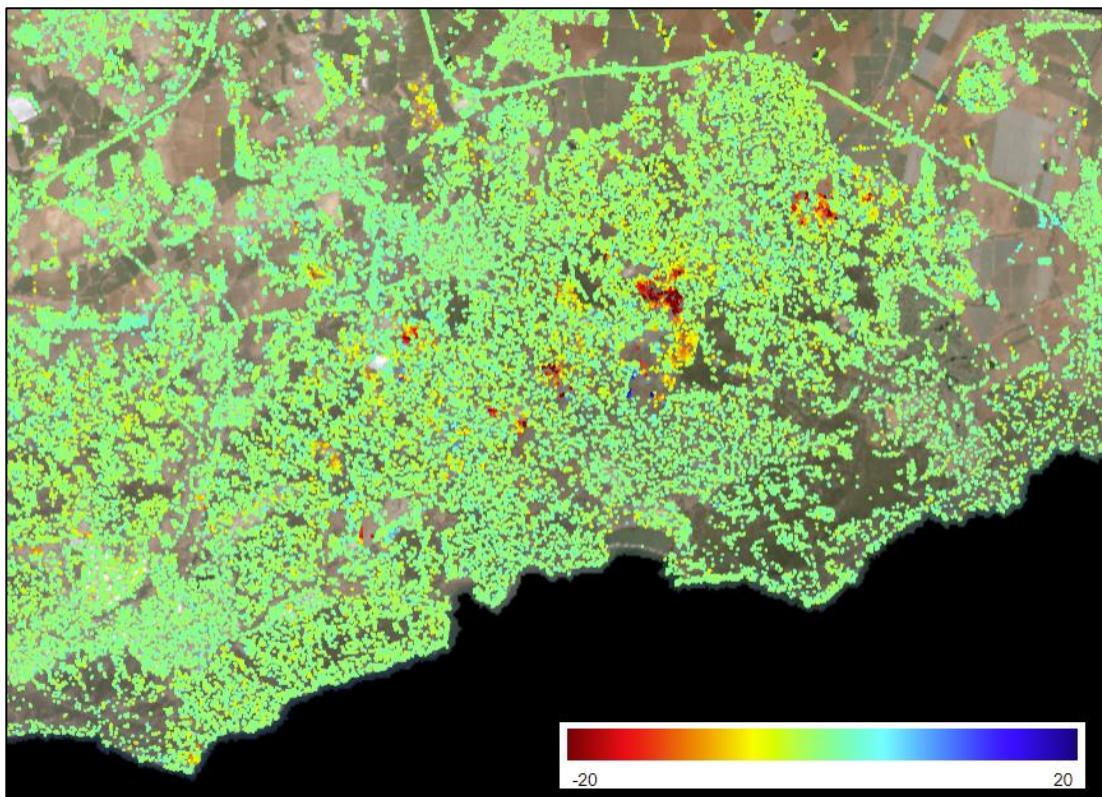
Martín-Crespo, T., Gómez-Ortiz, D., Martín-Velázquez, S., Martínez-Pagán, P., De Ignacio, C., Lillo, J., Faz., A., 2018. *Geoenvironmental characterization of unstable abandoned mine tailings combining geophysical and geochemical methods (Cartagena-La Union district, Spain)*. Engineering Geology, Volume 232, Pages 135-146, ISSN 0013-7952, <https://doi.org/10.1016/j.enggeo.2017.11.018>.

López-Vinielles, J., Fernández-Merodo, J.A., Ezquerro, P., García-Davalillo, J.C., Sarro, R., Reyes-Carmona, C., Barra, A., Navarro, J.A., Krishnakumar, V., Alvioli, M., 2021. *Combining Satellite InSAR, Slope Units and Finite*

Element Modeling for Stability Analysis in Mining Waste Disposal Areas. Remote Sens. 2021, 13, 2008.
<https://doi.org/10.3390/rs13102008>

Validation Area EGMS coverage

The entire area shows good coverage by EGMS.

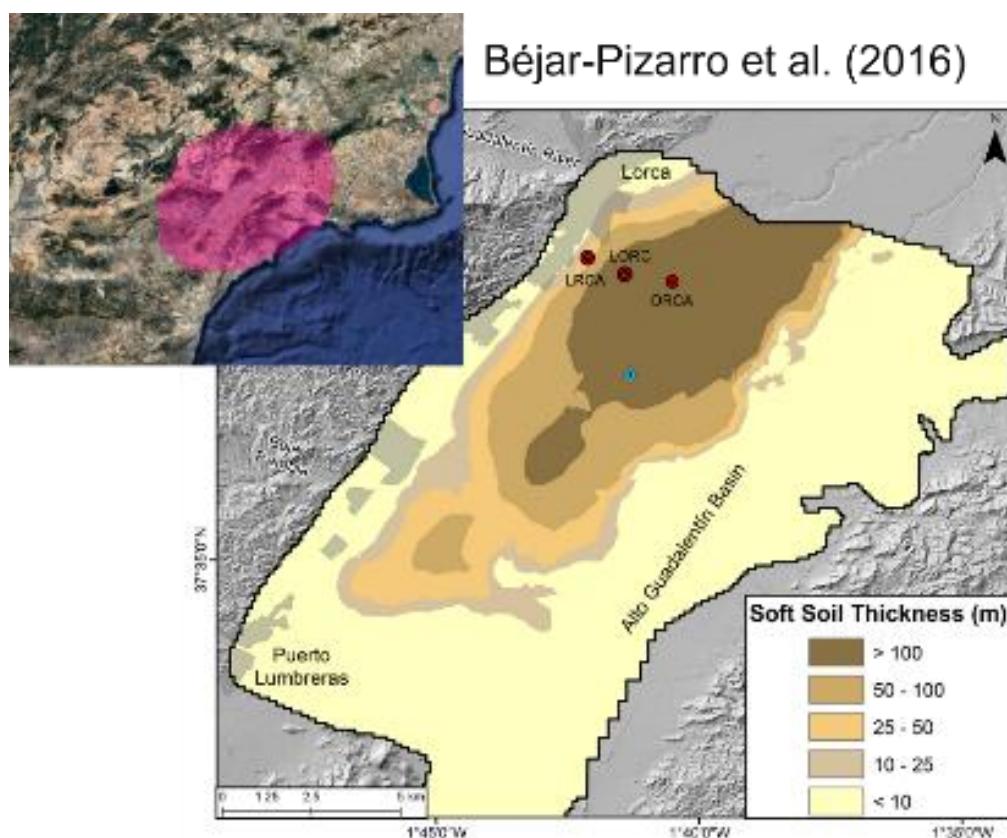


Test site ID / Name

VA4_3 – Alto Guadalentín, Spain

Validation area characteristics

The Alto Guadalentín valley is an intra-montane basin located in southeast Spain, filled by Neogene-Quaternary sediments, in which the build-up of alluvial deposits mostly comes from the transportation dynamics of the Guadalentín River. The basin contains a multi-layer aquifer system covering an area of approximately 277 km², subjected to water exploitation during the past 50 years. Groundwater withdrawal reduces pore water pressure in voids between soil particles. Consequently, the effective stress on soil increases, resulting in a gradual compaction of the sediments that causes the lowering of the ground surface.



Validation Area target phenomena

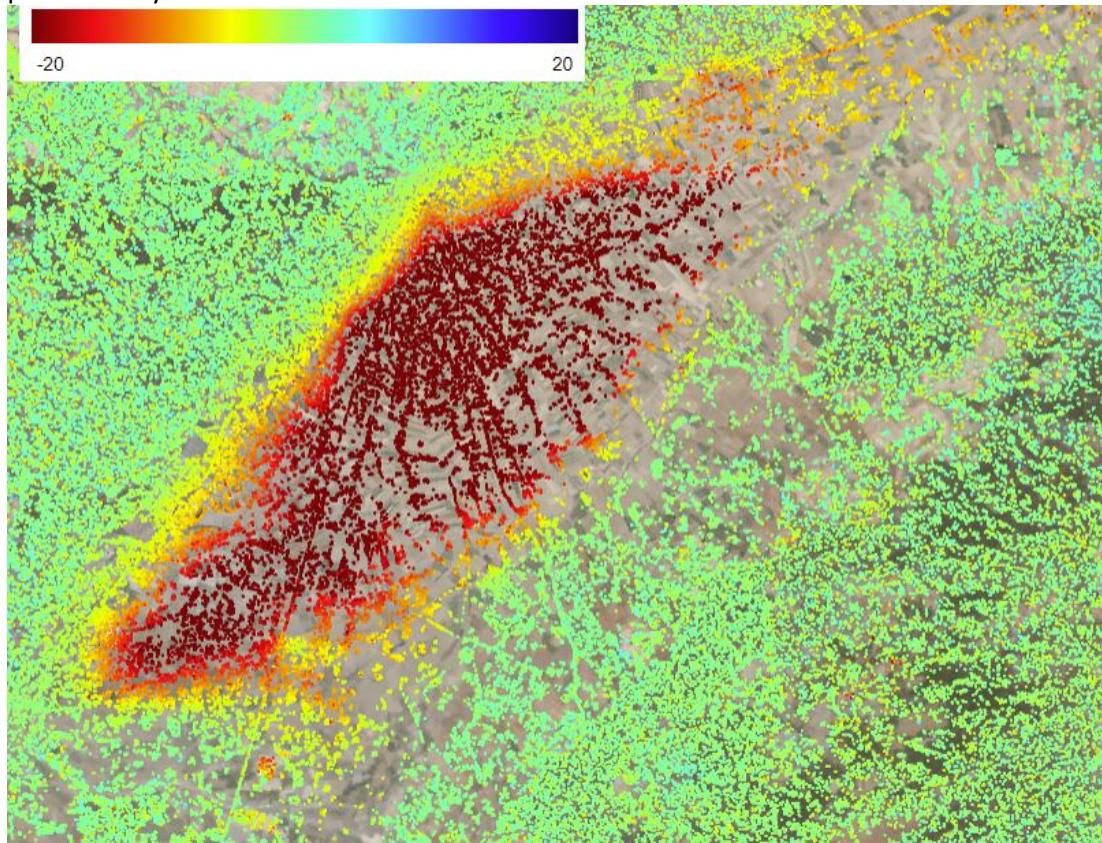
The development of the agriculture industry and the accelerated population growth triggered the reduction of the piezometric levels, which have reached >200 m of drop.

References:

M. Béjar-Pizarro, C. Guardiola-Albert, R.P. García-Cárdenas, G. Herrera, A. Barra, A. López Molina, S. Tessitore, A. Staller, J.A. Ortega-Becerril, R.P. García-García., 2016. *Interpolation of GPS and geological data using InSAR deformation maps: method and application to land subsidence in the alto Guadalentín aquifer (SE Spain)*. Remote Sens., 8 (11).

Validation Area EGMS coverage

The area shows in general good coverage by EGMS. In the agricultural areas measurement point density is coarser.



Test site ID / Name

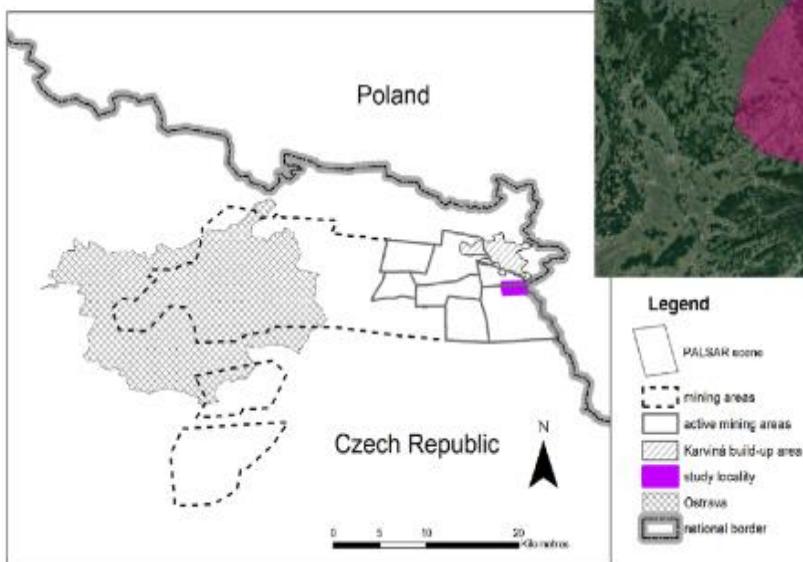
VA4_4 – Silesia coal mine region, Czech Republic / Poland

Validation area characteristics

The Upper Silesian Coal Basin (USCB) is one of the largest hard coal mining areas in Europe. It is located at the border between Czech Republic and Poland and covers an area of over 6000 km². Mining activity started in the 19th century. Urban growth followed the mining industry development, reaching 37 towns with almost three million inhabitants nowadays.

The most common mining method in USCB is longwall coal mining. Usually, the excavated coal layer is 2.5 m thick, 250 to 400 m long, and about 680 m deep.

Kadlečík et al. (2015)



References

Kadlečík, Pavel & Kajzar, Vlastimil & Nekvasilová, Zuzana & Wegmüller, Urs & Doležalová, H., 2015. *Evaluation of the subsidence based on dInSAR and GPS measurements near Karviná, Czech Republic*. AUC GEOGRAPHICA. 50. 51-61. 10.14712/23361980.2015.86.

Validation Area target phenomena

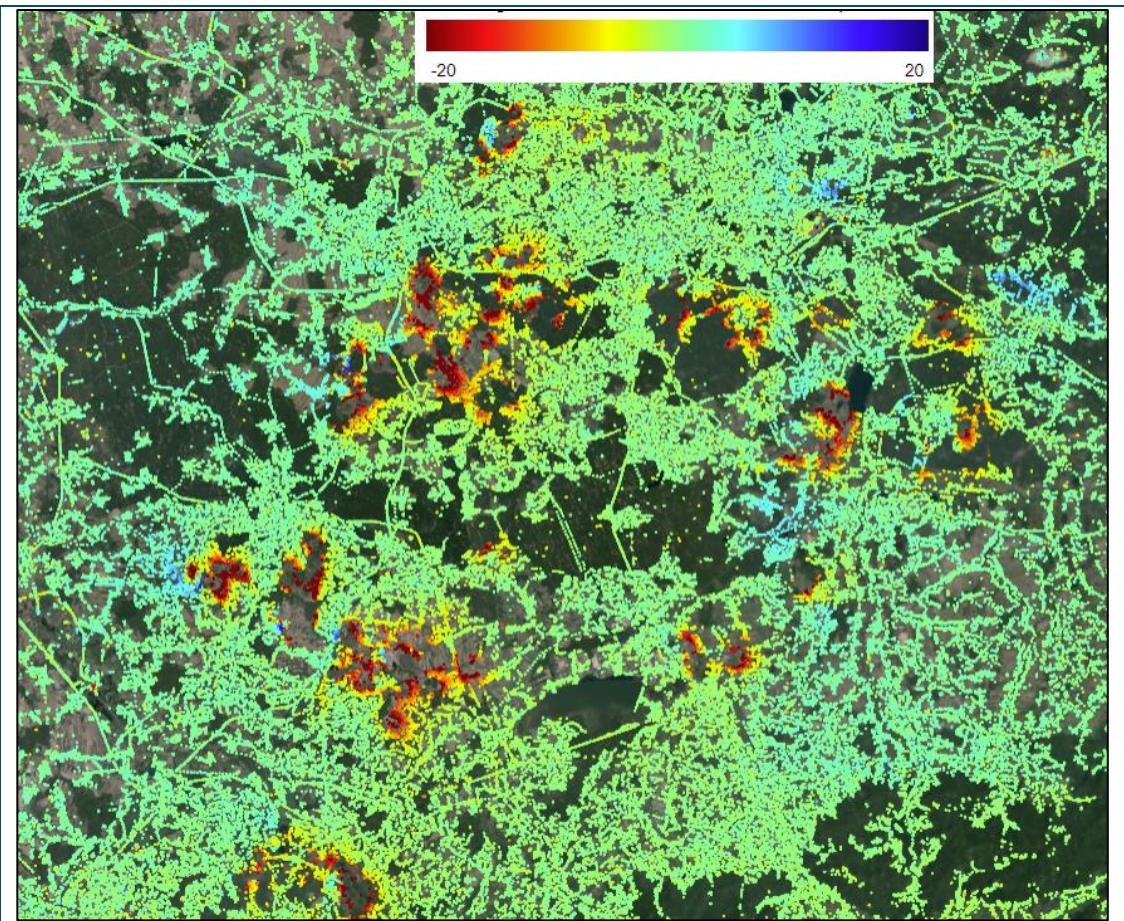
The main source for ground deformation (subsidence and heave) in the area is related to underground coal mining. Subsidence can reach up to 70% of the excavated coal layer, which represents a 0.75–2.0 m displacement for every layer. Taking into account that multi-layer exploitation is common, subsidence depressions up to 40 m are found in USCB. It is estimated that an area of more than 300 km² is already affected by mining subsidence. Even if most of these areas are used as agricultural and forest lands, ground deformation recurrently damages urban structures and infrastructures such as buildings, roads, drainage networks, and pipelines.

References

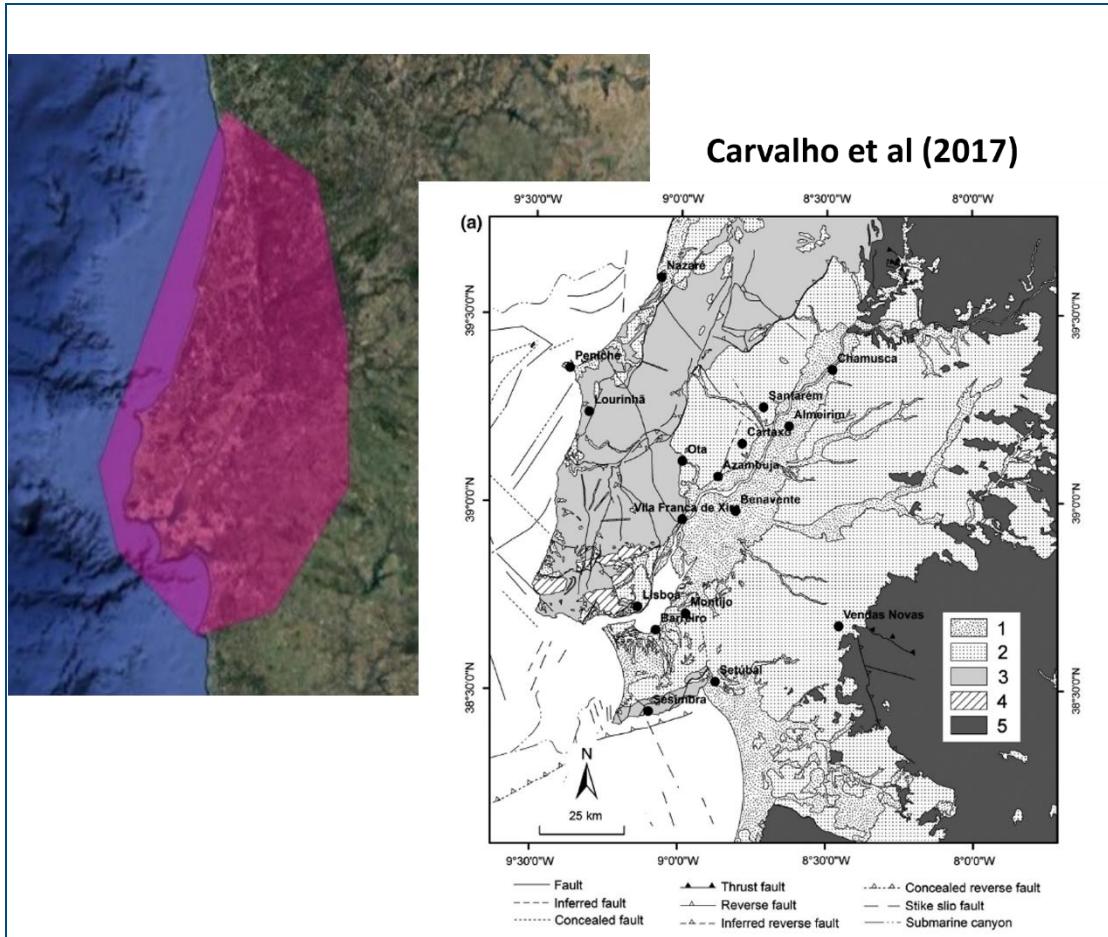
Przyłucka, Maria & Herrera, G. & Graniczny, Marek & Colombo, Davide & Bejar, Marta, 2015. *Combination of Conventional and Advanced DInSAR to Monitor Very Fast Mining Subsidence with TerraSAR-X Data: Bytom City (Poland)*. Remote Sensing. 7. 5300-5328. 10.3390/rs70505300.

Validation Area EGMS coverage

There is good coverage by the EGMS of the edges of the affected areas, both for areas with subsidence and for areas with heave. The centres of the affected areas do, however, not show coverage; the current hypothesis being that these areas deform too fast. Vegetated areas in the region (forests, agricultural land) are not well covered either, however, this is expected.



Test site ID / Name
VA4_5 – Lower Tagus Valley Fault System, Portugal
Validation area characteristics
The Lower Tagus Valley Fault System is a set of active tectonic faults near Lisbon, Portugal. It has long been associated with damaging earthquakes that affected the Greater Lisbon Area in historical times. These include a poorly documented earthquake that occurred in 1344, a relatively well-documented earthquake in 1531, and the most recent M6.0 1909 earthquake. The seismic hazard poses a risk to population and infrastructure and has a potential impact on CO ₂ storage, geothermal and underground energy storage projects. The area is also subject to over-exploitation of groundwater resources and construction activities.
References:
Carvalho, J., Pinto, C., Dias, R., Rabeh, T., Torres, L., Borges, J., Torres, R., Duarte, H., 2017. <i>Tectonic Evolution of an Intraplate Basin: the Lower Tagus Cenozoic Basin, Portugal</i> . Basin Research. 29. n/a-n/a. 10.1111/bre.12193.
Validation Area target phenomena
Several studies reveal considerable ground subsidence. Estimated earthquake slip rates are too low to explain observed subsidence. It is suspected that the ground subsidence is caused by compaction of a clay-rich aquitard, led by over-exploitation of adjacent aquifers. Other less intense subsidence areas may be also due to construction activities.

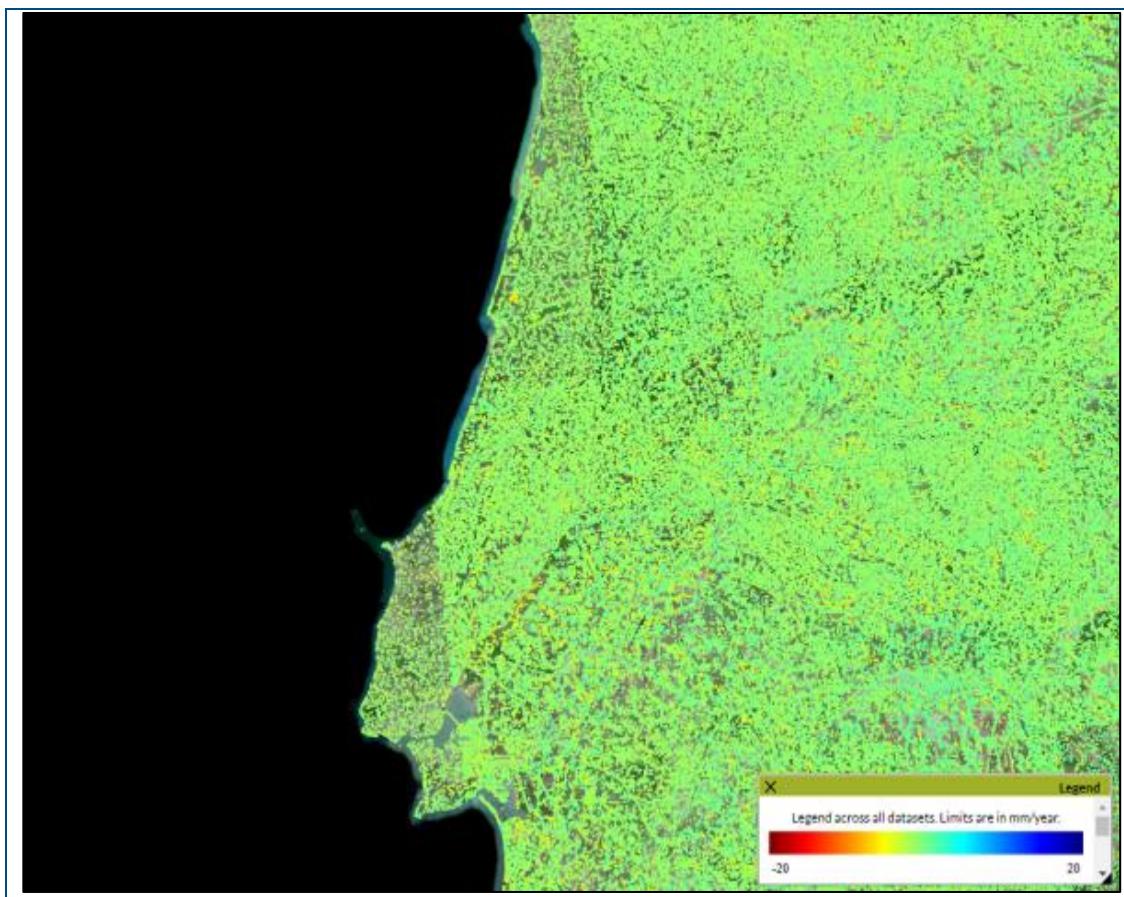


References:

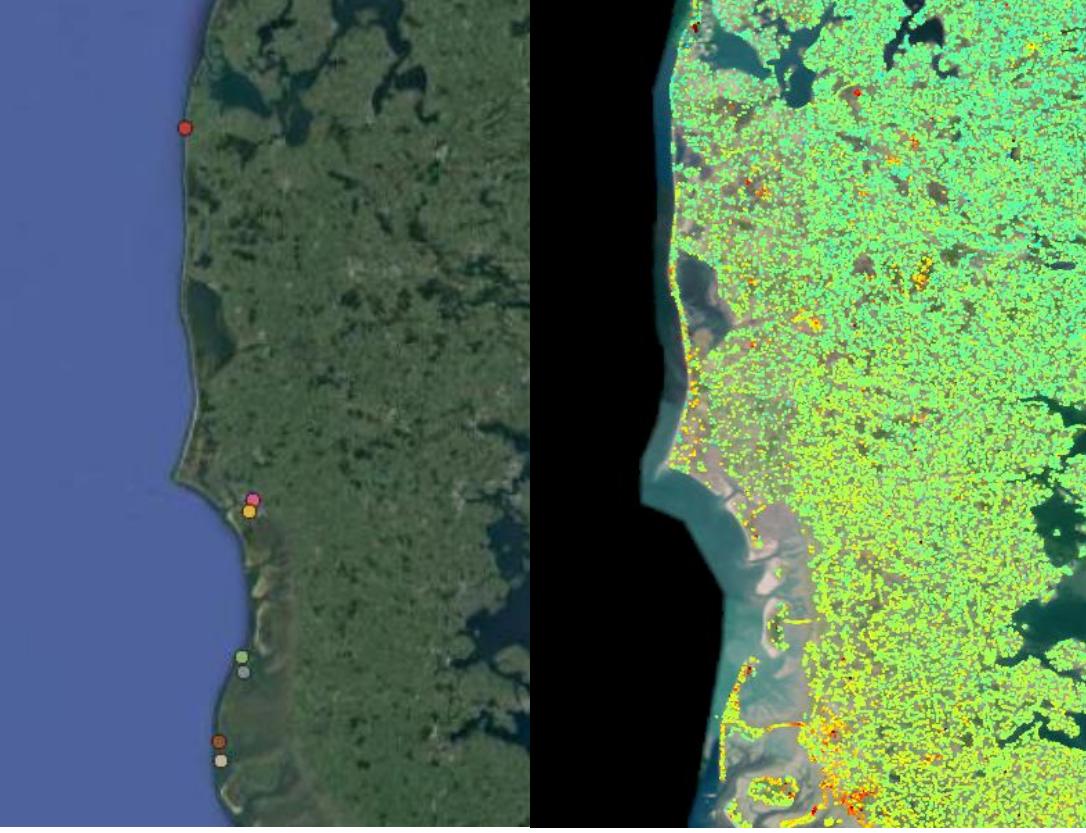
Sandra I.N. Heleno, Luís G.S. Oliveira, Maria J. Henriques, Ana P. Falcão, José N.P. Lima, Geraint Cooksley, Alessandro Ferretti, Ana M. Fonseca, João P. Lobo-Ferreira, João F.B.D. Fonseca., 2011. Persistent Scatterers Interferometry detects and measures ground subsidence in Lisbon. *Remote Sensing of Environment*, Volume 115, Issue 8, 2152-2167, ISSN 0034-4257, <https://doi.org/10.1016/j.rse.2011.04.021>.

Validation Area EGMS coverage

There is good coverage by the EGMS urban areas. Vegetated areas (forests, agricultural land, city parks) are not well covered, which is expected.



2.5 Comparison with GNSS data

Test site ID / Name
VA5_1 – West Jutland, Denmark
Validation area characteristics
Jutland is a large peninsula that contains the mainland regions of Denmark. It separates the North and Baltic seas, and borders Germany to the south. In the west coast of the Jutland region, the soil is mostly composed of sand and clay. Jutland's terrain is flat, with a slightly elevated ridge down the central parts. The largest hills (~150m) are in the east. The west has a very low topography with some areas being below the average sea level. This area has been monitored with GPS stations since around the year 2010.
Validation Area target phenomena
The phenomenon targeted is coastal subsidence. Although Denmark is uplifting due to the post-glacial, large parts of the coastal region are subsiding due to local phenomena. For example, the harbour in Esbjerg (Jutland region) seems to be subsiding. Other subsidence phenomena have also been reported in the town of Thyborøn.
Validation Area EGMS coverage
GPS station provided by DTU (left) and coverage of product levels calibrated/ortho (right) 

Test site ID / Name

VA5_2 – Canary Islands, Spain

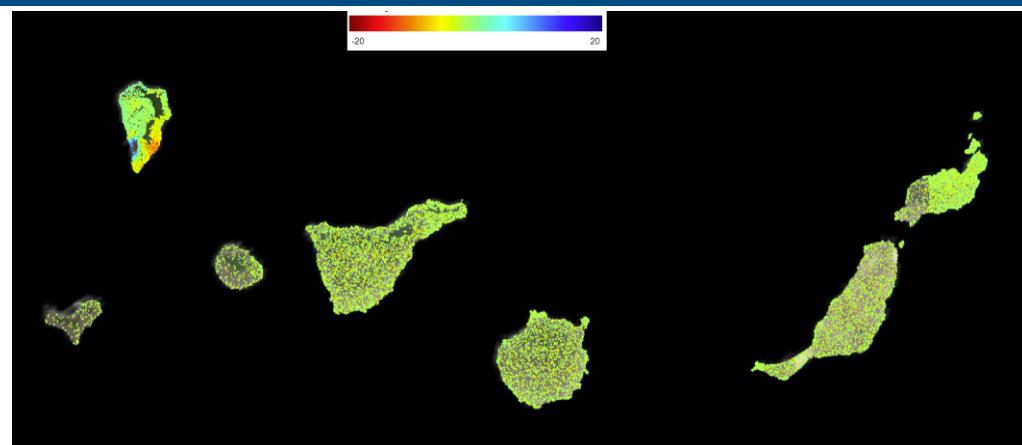
Validation area characteristics

The Canary Islands is a populated outermost Spanish region and one of the most popular touristic destinations in Europe. More than 2 million people live and work in the archipelago, resulting in an average population density three times greater than the rest of Spain. The archipelago is one of the major volcanic oceanic island groups of the world and have a long magmatic history, which began at the bottom of the ocean more than 40 million years ago. This volcanic archipelago is constructed on the passive continental margin of the African Plate on Jurassic oceanic lithosphere and comprises seven main volcanic islands that form a chain extending for some 500 km across the East Atlantic Ocean.

Validation Area target phenomena

Most of the historical eruptions in the Canary Islands have been short lived (from few weeks to few months) basaltic, strombolian to violent strombolian eruptions, which have generated scoria cones of different sizes and lava flows of different extend. Sixteen historical eruptions have been documented in the Canarian Archipelago to date. The last event occurred in September 2021 in La Palma and lasted 85 days. It covered more than 1228 Ha and destroyed around 1700 buildings. Among the islands, Gran Canaria and La Palma have been chosen as validation sites.

Validation Area EGMS coverage



GPS location in La Palma and Gran Canaria showed as coloured circles:



Test site ID / Name

VA5_3 – Lorca, Spain

Validation area characteristics

The Guadalentín basin, SE Spain, is one of the driest regions of Europe. This basin is a tectonic depression located in the eastern part of the Betic Cordillera, an alpine orogenic belt resulting from the collision between the African and Iberian plates. The Alto Guadalentín detritic aquifer is located between the cities of Lorca and Puerto Lumbreras. The continuous pumping of groundwater in the aquifer, mainly for agricultural use, led to a decrease in the piezometric levels of more than 200 m since 1975, resulting in the overexploitation of the aquifer and land subsidence.

References:

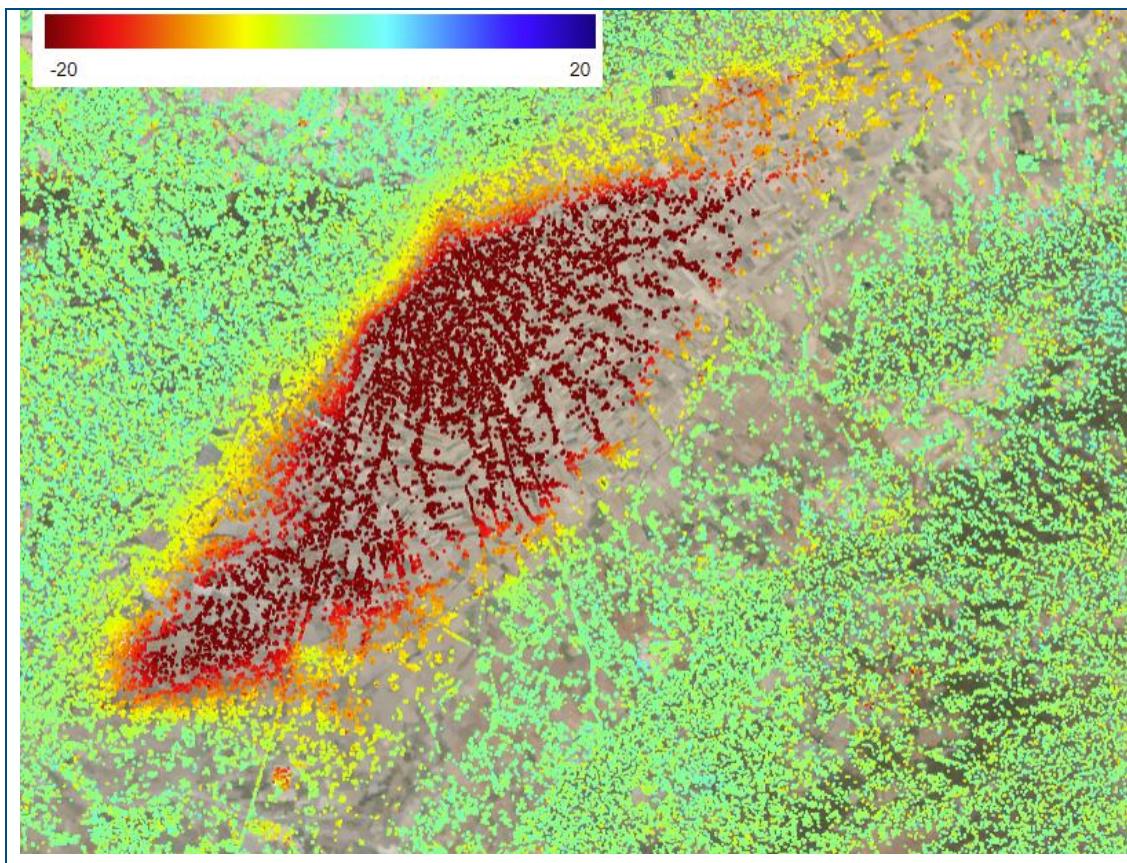
M. Béjar-Pizarro, C. Guardiola-Albert, R.P. García-Cárdenas, G. Herrera, A. Barra, A. López Molina, S. Tessitore, A. Staller, J.A. Ortega-Becerril, R.P. García-García., 2016. *Interpolation of GPS and geological data using InSAR deformation maps: method and application to land subsidence in the alto Guadalentín aquifer (SE Spain)*. Remote Sens., 8 (11).

Validation Area target phenomena

Lorca is affected by subsidence triggered by water overexploitation. It has been studied using different techniques, such as GNSS and InSAR. Accumulated vertical deformation close to the city of Lorca is around 24 cm but larger in the centre of the basin, ranging to 12 cm/year.

Validation Area EGMS coverage

Area is well covered by EGMS on all product levels with observed displacement over a vast area:



2.6 Comparison with in-situ monitoring data

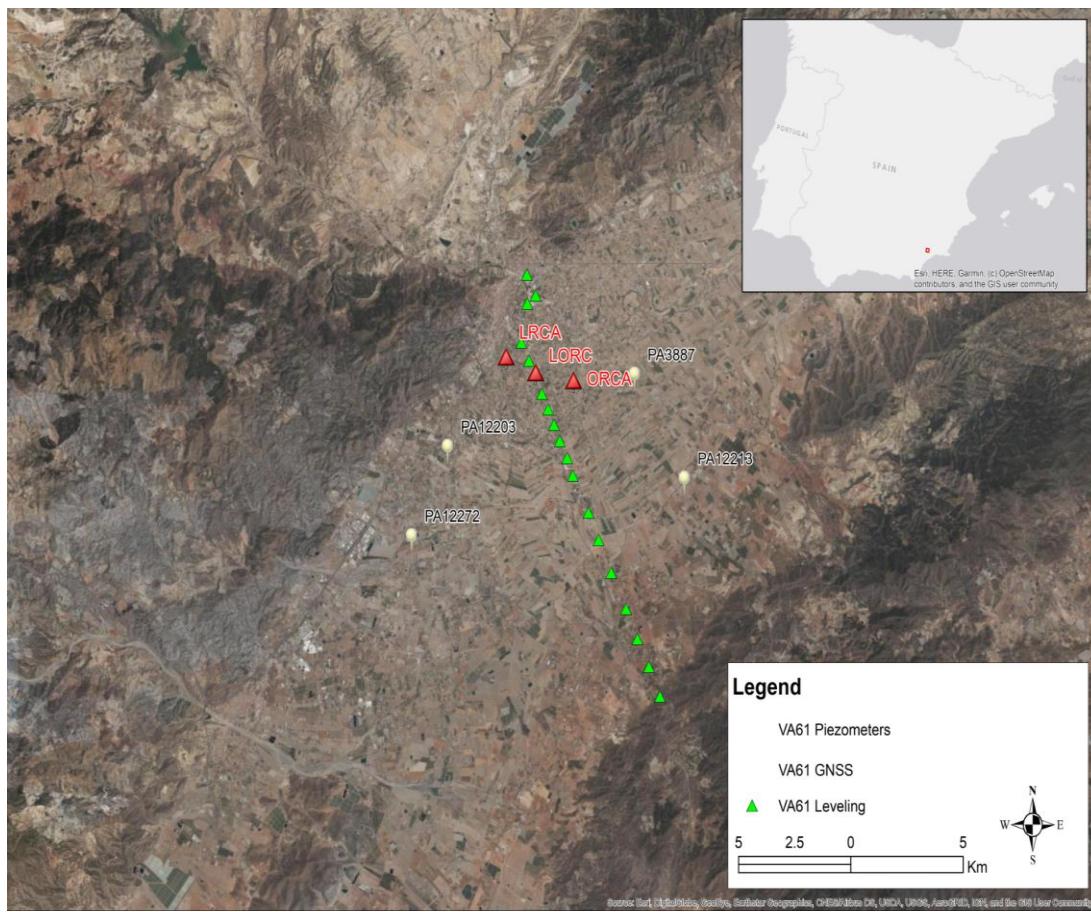
Test site ID / Name

VA6_1 – Lorca, Spain

Validation area characteristics

The Alto Guadalentín aquifer is located in the Murcia Region, Southeast Spain. The aquifer has an extension of 273 km² with altitudes varying from 251 m a.s.l. to 551 m a.s.l. Land uses in the study area are mainly agricultural (mainly irrigation crops) (91.0%), forest areas (4.5%) and artificial (4.5%), where Lorca and Puerto Lumbreras are the two principal urban centres. The Segura Hydrographic Demarcation (SHD) is the organism that manages both surface and ground water bodies in the area. On 2006, the European Parliament approved a new directive (2006/118/EC) which reinforces some key aspects of the 2000 Water Framework Directive dealing with groundwater. SHD officially declared that Alto Guadalentín aquifer was at risk of not reaching the “good status” by 2015, and now by 2027.

As a consequence, restrictions to usage have been applied and no new pumping licences can be released.



Validation Area target phenomena

Several drought periods (since 1980 until today) coupled to anthropogenic activities responsible for the groundwater overexploitation and contamination of the Alto Guadalentín aquifer has led to a depletion of the ground water storage with an average decline of 90 m on piezometric level from 1990 to 2009. Recent studies using SAR from 1992 to 2012 images have revealed a continuous deformation pattern with one of the greatest velocities in

Europe (around 11 cm/yr) on its maximum area. The subsidizing area is closely related to the thickness of a soft soil layer, presented in the shallower part of the Plio-Quaternary materials and comprising low and very low permeability silts and clays.

Validation Area EGMS coverage

The ascending tracks required to cover this location are the A103 and A001, whereas for the descending is the D008.

Test site ID / Name

VA6_2 – Turow mine, Czech Republic / Poland

Validation area characteristics

The Turow mine which is located in the Lower Silesia District, close to the German and Czech borders is the second largest in Poland. Its estimated lignite reserves are equal to 760 mln tons, with an annual production of 27.7 mln tons.

The Turow mine supplies coal mainly to the nearby Turow plant, which generates 8% of Poland's energy supplies. In 2022 the Czech government accepted 45 million euro in compensation from the Polish government and coal company PGE, in exchange for dropping its lawsuit over their illegally operating Turów coal mine at the EU court of justice (CJEU). Despite the EU court is hitting the Polish government with a 500,000 euro daily fine (amounting to a total of 68 million euro), the owner of both installations, PGE Group plans to continue mining at the location until 2044.

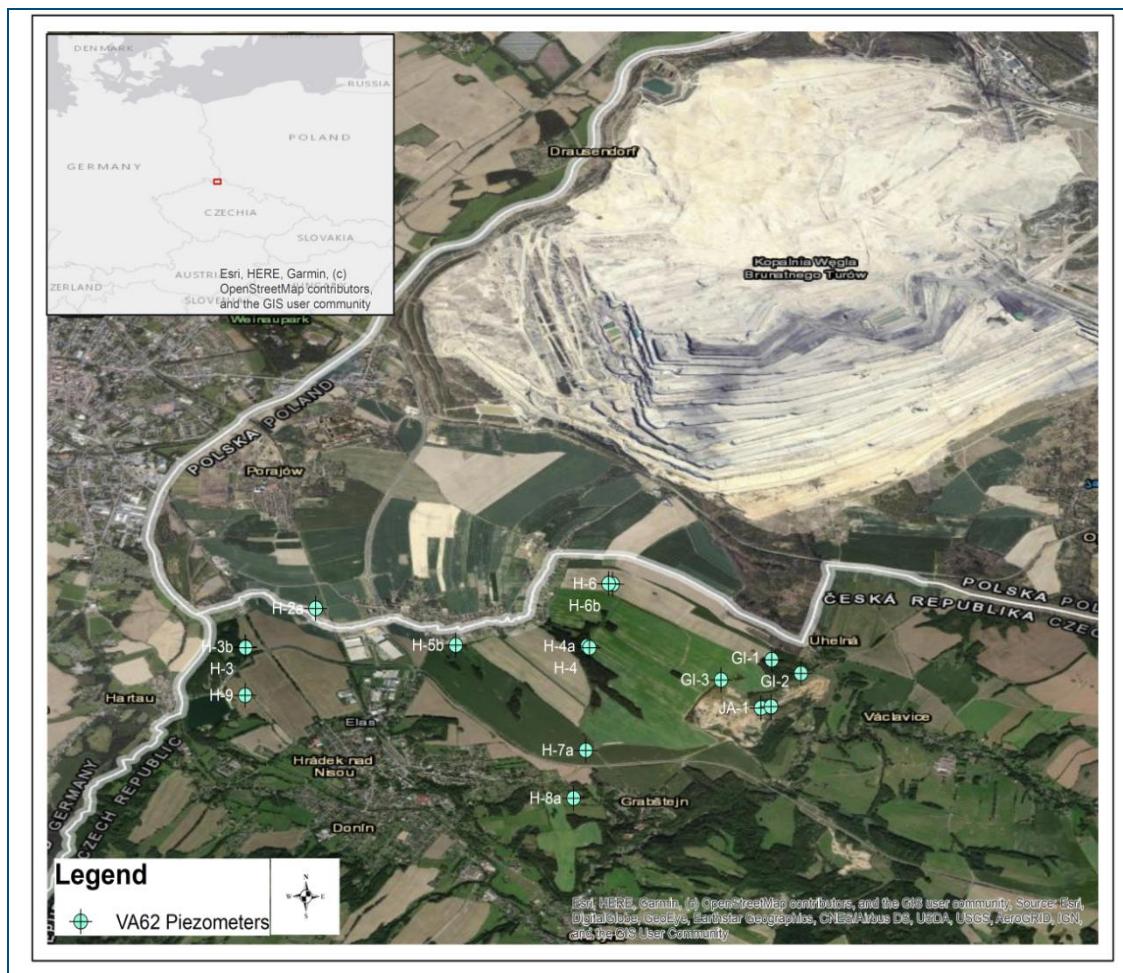
Validation Area target phenomena

The mining activity is depleting water supplies and damaging nearby houses (due to induced subsidence) in Germany and Czech Republic. That is why the Czech Republic built an extensive network of water boreholes for the monitoring of Turow mining impacts in the surroundings of the open-pit lignite mine, near the Czech-Polish border (18 boreholes 1997-2021). This network is being expanded to 36 boreholes from 2021.

On the German side, hydrogeological monitoring of part of the Zittau Basin indicates that the upper part of the aquifer is gradually receding while at the same time the deeper aquifer is progressively being drained. The entire subsidence process can only stop with the cessation of coal extraction and the dewatering of the Turow deposit.

Validation Area EGMS coverage

The ascending tracks required to cover this location are the A146 and A073, whereas for the descending are the D022 and D095.

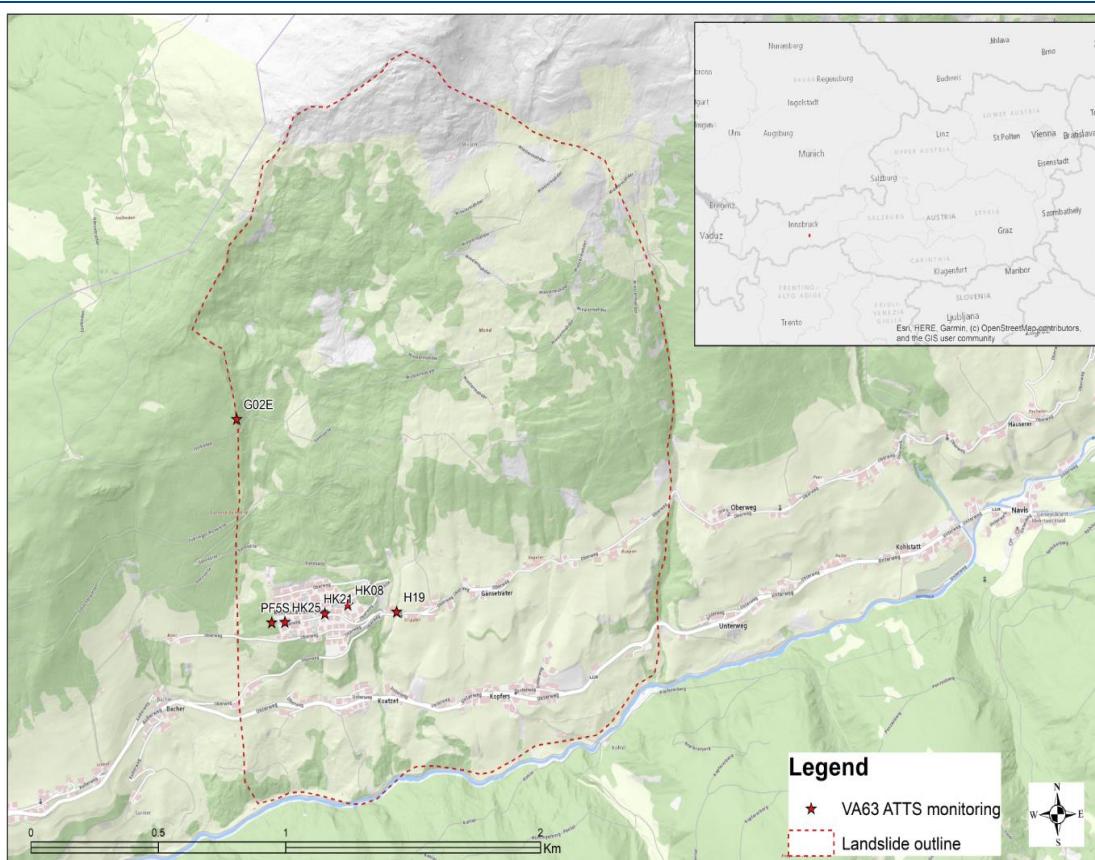


Test site ID / Name

VA6_3 – Navis valley, Tyrol, Austria

Validation area characteristics

Kerschbaumsiedlung is a residential estate located on the western part of the municipality of Navis on the south slope of mountainous region of the Misljoch. Since 2012, GPS surveying has demonstrated that part of this slope is moving up to 3 cm/yr. Twelve buildings of a total of 84 are affected by the slope movement. The houses show clear structural damages, and one of them has become inhabitable and had to be demolished. At the end of the 80s, work started to build on an urban settlement on a slope above the Naviser Oberwegs. After 10 years, the first cracks appeared on the streets and buildings of the Kerschbaumsiedlung; in 2001 hydrogeological investigations started. In order to understand the process and the causes of the slope movement and to be able to introduce efficient remediation measures, extensive testing and monitoring activities were carried out in the years 2012 - 2014.



Validation Area target phenomena

On the upper ridge, mountain deformation phenomena such as normal faults, tension cracks and trenches are taking place. The middle slope shows, particularly in the west of the large-scale slope movement, an irregular, humped terrain with two extended earthflows/-slides bodies. The described terrain features are unambiguous signs of gravitational mass processes from the head to the foot of the slope, which can be described as a deep-seated rock slope deformation.

Validation Area EGMS coverage

The ascending tracks required to cover this location is the A117, whereas for the descending is the D168.

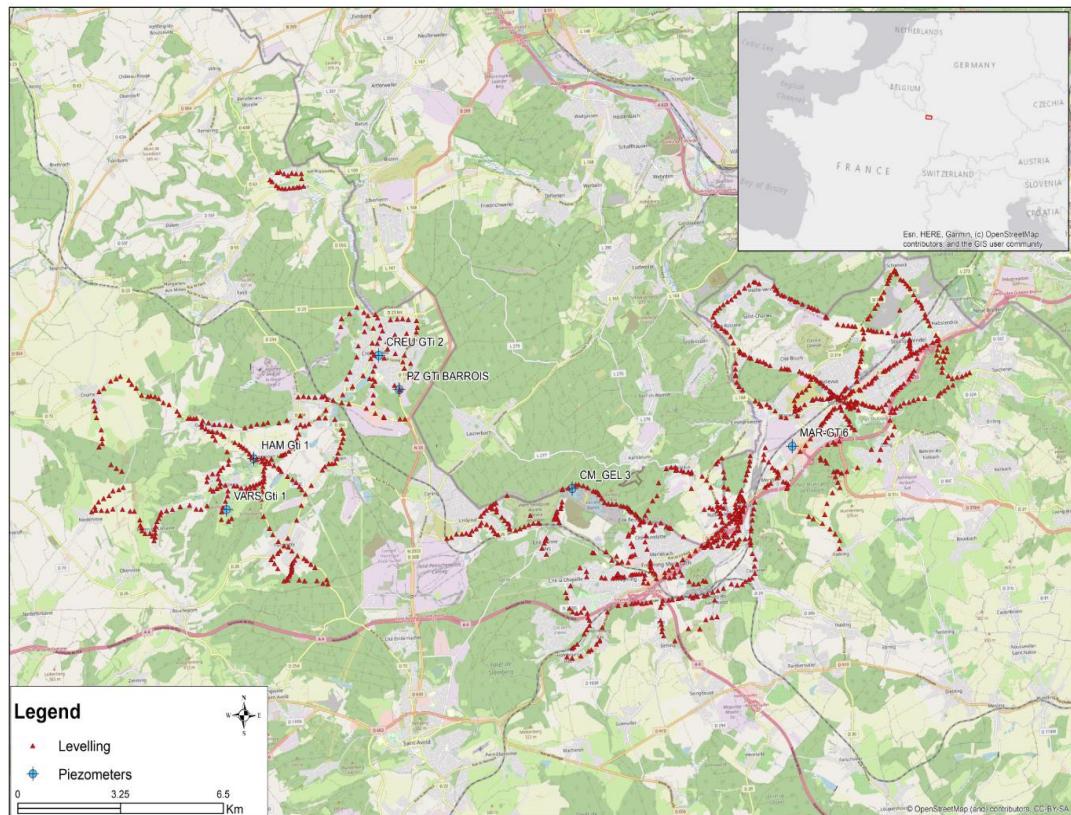
Test site ID / Name

VA6_4 – Freyming-Merlebach, France

Validation area characteristics

Historical levelling results reported by the GIAM group (2007) suggested that broader scale subsidence in the Lorraine coal region started prior to 1961. Rates of subsidence varied from a few mm/year to about 1 m/year and the phenomenon went on until up to 2004 when mining activities were interrupted. Since then, other concerns started to raise because the city of Freyming-Merlebach is experiencing uplifts due to natural water filling in former underground coal mines. Monitoring campaigns based on annual levelling measurement are carried out to measure the uplift of the areas, whereas piezometric measurement at the slag heap and the ponds are taken monthly check of the rise of the water table. On the other hand,

a series (monthly, 4 times a year and 2 times a year) of geochemistry analysis evaluate the water quality at the entrance, at the exit of the ponds and once discharged into the superficial water networks.



Validation Area target phenomena

The phenomenon of uplift, caused by natural water filling the abandoned underground galleries, continues to affect the entire basin, which spans an area of approximately 320 km². To control groundwater rise and protect the drinking water supply, the BRGM began installing pumping systems in 2009 (up to 3 by 2017). These systems inject fresh water into galleries to dilute mineral concentrations before the water is treated in natural ponds and discharged into surface water networks.

Validation Area EGMS coverage

The ascending tracks required to cover this location are the A117 and A044, whereas for the descending are the D168 and D095.

2.7 Evaluation XYZ and displacements with Corner Reflectors

Test site ID / Name
VA7_1 – Thyborøn, Denmark
Validation area characteristics
The Thyborøn area is located at the west coast of Denmark. Thyborøn is built on landfill and soft sediments and is expressing subsidence with magnitudes above 7mm/year happening in the south-eastern part of the town. This area has been surveyed with precision levelling every 3 years since 2003.
Validation Area target phenomena
Subsidence due to consolidation
Validation Area EGMS coverage
Area is covered and subsidence pattern can be observed together with the three CR's visible in the EGMS time-series
<p>A satellite map of Thyborøn, Denmark, showing land subsidence patterns. The map is color-coded to represent subsidence rates in mm/year, with a legend ranging from -20 (red) to 20 (blue). A white circle highlights a specific area in the bottom right. Three black triangles mark the locations of corner reflectors (CRs) used for surveying. The map shows a mix of green fields, a road, and coastal areas.</p>

Test site ID / Name

VA7_2 – Jettan, Indre Nordnes and Gamanjunni, Norway

Validation area characteristics

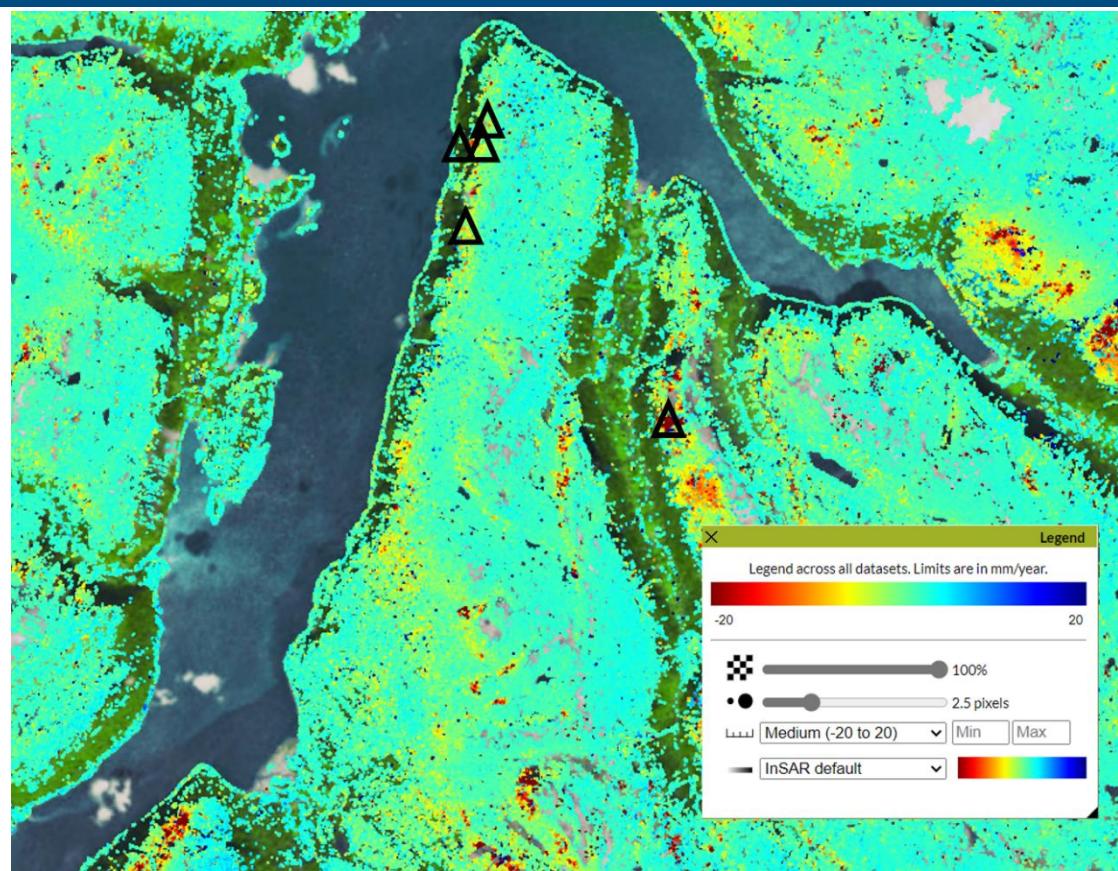
Indre Nordnes and Jettan are two an unstable mountain ranges located on the east side of the Lyngenfjord in Kåfjord municipality in Troms and Finnmark. Landslides in these areas can trigger tidal waves that impact nearby settlements and infrastructure.

Gámanjunni is an unstable mountain section, or a compound slide located on the east side of Manndalen in Kåfjord municipality, Troms and Finnmark. A compound slide is characterised by a large coherent slide block with steep sliding surfaces. A landslide from Gámanjunni 3 can cross Manndalselva, reach buildings, and dam the river.

Validation Area target phenomena

Landslides

Validation Area EGMS coverage



Test site ID / Name

VA7_3 – Calern, France

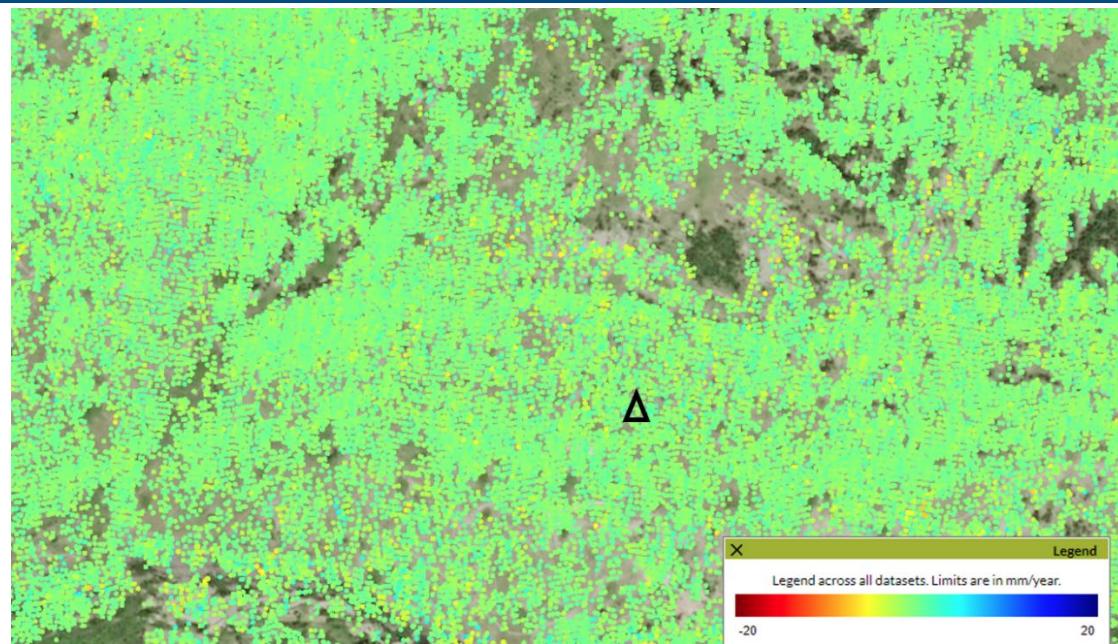
Validation area characteristics

Calern is located on a calcareous plate of 20 km² in the Grasse hinterland located at Altitude 1270m. Yearly local measurements contribute to ITRF, the International Terrestrial Reference Frame. Final precision: < 5mm E/N, < 1mm U

Validation Area target phenomena

Kart soil: risk of landslide and seasonal subsidence due to seasonal hydraulic load

Validation Area EGMS coverage





3. LIST OF ABBREVIATIONS

ASC	Ascending
ATTS	Automatic Tracking Total Station
CLC	Corine Land Cover
CLMS	Copernicus Land Monitoring Service
CNIG	Centro Nacional de Información Geográfica
CR	Corner Reflector
CRS	Coordinate Reference System
DEM	Digital Elevation Model
DESC	Descending
DPSM	Département Prévention et Sécurité Minière
DTU	Technical University of Denmark
EEA	European Environment Agency
EGMS	European Ground Motion Service
GMS	Ground Motion Service
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
InSAR	Interferometric Synthetic Aperture Radar
INPIRE	INfrastructure for SPatial InfoRmation in the European community
ITRF	International Terrestrial Reference Frame
NGI	Norwegian Geotechnical Institute
NGU	Norwegian Geological Survey
P-SBAS	Parallel Small Baseline Subset
TS	Time Series



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