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Monitoring deformations related to geological risks with InSaR data – the MOMPA project

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Abstract. Co-financed by the Interreg V Program in Spain-France-Andorra (POCTEFA) the European project MOMPA (MONitoring of ground Movements and Action Protocol) study the landslide hazard in the Eastern Pyrenees. It groups together scientific partners from CTTC (Telecommunications Centre of Catalonia), ICGC (Cartographical and Geological Institute of Catalunya) IEA (Andorran Research Institute), and Cerema (Centre for studies and expertise on risks, the environment, mobility, and development). This cross-border project provides the expertise of four partners, which are specialized in remote sensing and techniques of risk analysis and management. More specifically, the goal of this project is to improve risk management by evolving from a "reactive" approach to a "proactive" one that is rarely used today because of its financial cost. To identify movements, the technique of interferometric SAR (InSAR) based on satellite images is used. This technique is sensitive to very small ground deformations and allows early detection of movements.

1. Introduction

Landslides are one of the most expensive hazards considering their impact on infrastructures and their direct and indirect cost. In situ monitoring is inevitably localized on specific known sites and cannot cover (very) large areas. The high cost of in situ monitoring of land movements influences the management of the associate geological risks, which is often reactive: actions are taken when problems are evident. Furthermore, landslides inventories are not complete or exhaustive and do not cover areas far from human structures. In the meantime, more and more satellite images that cover large areas are accessible at a reasonable cost, but an important question remains about their resolution and accuracy: can they be used to identify and/or to monitor landslide?

The objective of MOMPA is to improve risk management, to contribute to evolve from a reactive approach to a proactive one. The innovation element of the project is applying the interferometric SAR (InSAR) technique, based on satellite imagery, for the enhancement of geological risk management. This technique, which is sensitive to small terrain deformations, can be used for an early detection of movements, monitoring and risk assessment [1-3].

The MOMPA project started the 1st of December 2019 and will finish in May 2022. This paper focuses on the first results obtained in the French area.



2. General presentation of MOMPA Project

The MOMPA project (MOnitorización de Movimientos del terreno y Protocolo de Actuación - MOnitoring of ground Movements and Action Protocol) has been 65% co-financed by the European Regional Development Fund through the Interreg V-A Spain-France-Andorra programme (POCTEFA 2014-2020). POCTEFA aims to reinforce the economic and social integration of the French – Spanish –Andorran border. The study area of the project is located at the Eastern Pyrenees (figure 1), covering the whole Principality of Andorra, the Spanish areas of Alt Urgell and Cerdanya (Catalonia) and the French areas of Capcir and Conflent (Occitanie). The aim of the Project is to provide a useful technical-operational tool for risk prevention and management, at a cross-border level, based on satellite InSAR technique monitoring of ground movements. The tool includes two main elements: i) the assessment of the risk associated with active phenomena that affect structures and infrastructures and ii) the integration of the technique in an action protocol for Civil Protections. These results will be transferred to Civil Protections (associated partners of the project) and other organizations, such as local and regional Public Authorities.

The studied area presents two critical issues: it is not an easy area for what concerns the radar response, i.e. the obtainable results in terms of displacement map (velocity map and time series of deformation), which is the main input of the project, can be strongly limited. A second issue is the important differences of the available data in Andorra, Spain, and France.

The project will face the risk assessment starting from the regional scale displacement map (covering around 4,000 km²) and the obtention of Active Deformation Areas (ADA) map [4]. ADA are used as inputs to select movements with potential risk where focus the analysis at a local scale, based on traditional methods (i.e. basically photointerpretation and field work). Both the medium-resolution, free data, acquired by Sentinel-1 and the high-resolution data acquired by COSMO-SkyMed will be used in this project action.

Susceptibility and risk analyses associated to landslides will be performed integrating the information of the detected active zones (ADA) with the delimitation of geological phenomena. Two analyses will be performed in the whole area: the first one with the Sentinel-1 images, the second one with COSMO-SkyMed images.

Finally, at a few selected areas in each country action protocols based on satellite monitoring as a support of conventional monitoring will be proposed to Civil Protection Authorities. As an example, in Andorra; the specific case of “la Portalada” will be monitored: this huge landslide occurred in August 2019 and a slow movement up slope that could affect a main road located in the bottom of the valley still occurs. Because of the high interest for the local authorities to monitor and characterize the current movement of the slope located upper to the landslide scar eight passive and one active corner reflectors have been installed along the steep forested slope. The obtained data will be integrated in the prevention risk protocol already existing on this site.

3. First Data obtained on the French area

3.1. The French area under study – geographical and geological description

The studied area is in the Eastern Pyrenees (figure 1), covering the whole Principality of Andorra, the Spanish areas of Alt Urgell and Cerdanya (Catalonia) and the French areas of Capcir and Conflent (Occitanie).

The geology and geomorphology of the Conflent and Capcir and more generally of the Tet Valley are strongly linked to the Pyrenean orogeny. A first valley first dug into the base of the primary era consisting mainly of granites, gneiss, shale, marbles was then filled by a continental marine deposit of the Miocene. The present-day Tet Valley has dug in parallel and is marked by Pliocene progradation cones and Quaternary glacial deposits. The areas studied here are mainly shale areas from primary-era sea deposits accumulated over 250 million years and then metamorphosed following the uplifting of the Pyrenees (figure 2).

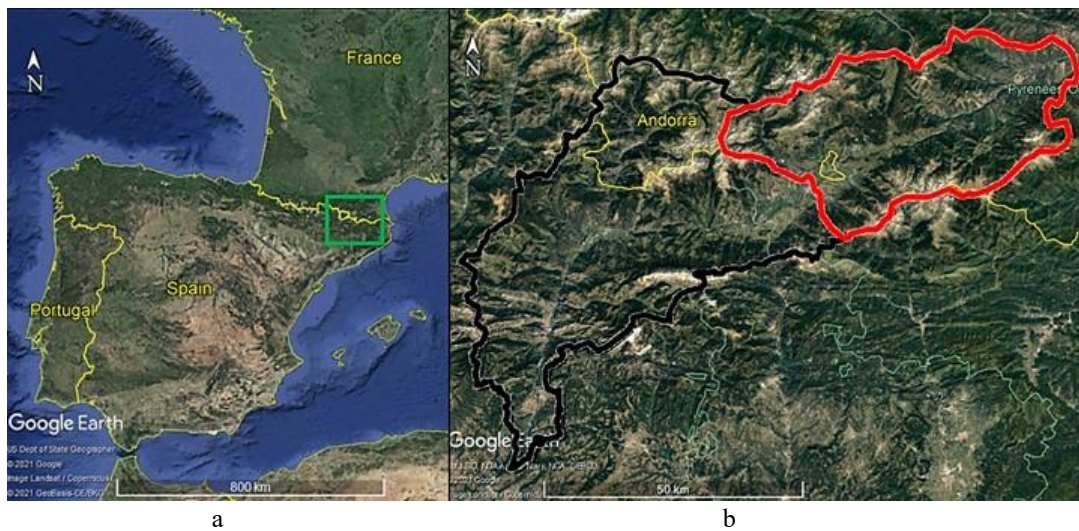


Figure 1. Studied area. a- regional scale; b- local scale.

The green square on figure 1a correspond to the whole figure 2b – On figure 2b the red area is the French covered area, the black area is the Spanish + Andorran covered area.

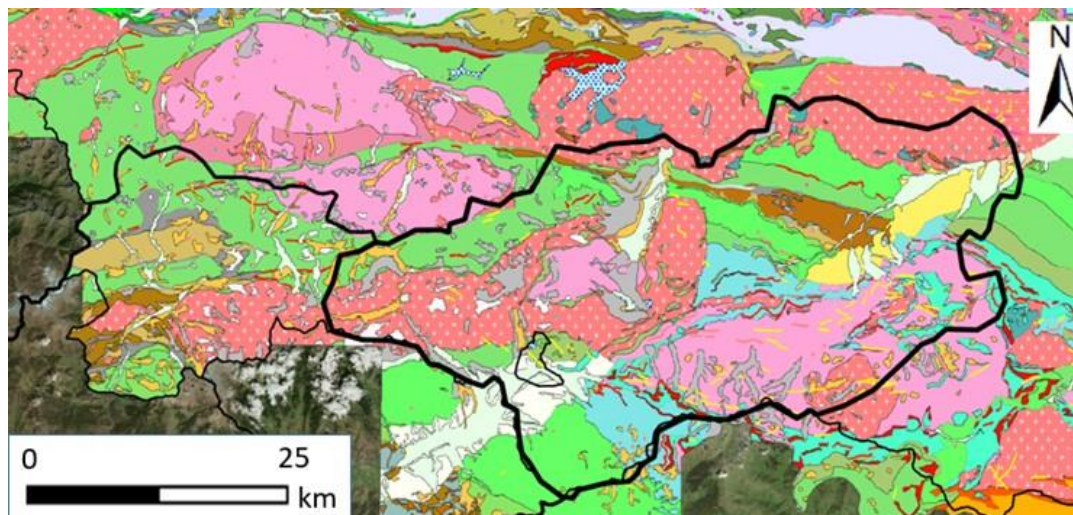


Figure 2. Geological map (1:250.000 scale) - the French studied area is black surrounded (based on www.infoterre.fr).

3.2. InSAR results on the French area

In charge of the first actions of the Interreg MOMPA project, the CTTC provided its expertise in the field of satellite interferometry (InSAR) to detect and monitor movements related to geohazards in the project area. From CTTC we have been provided by two kinds of maps derived from InSAR technique: the Deformation Activity Map (DAM) and the Active Deformation Areas MAP. The ADA map is the main input to focus deeper analysis on the most significant moving areas, which have a potential impact in terms of risk. The methodology used by the CTTC to obtain the DAM and ADA is described in [1], here we summarize the main characteristics of the two maps:

- The Deformation Activity Map, (that correspond to a type of velocity map) has been generated starting from Sentinel-1 data (a set of SAR images acquired at different times). The processing has been performed through PSIG, the PSI (Persistent Scatterer Interferometry) chain developed

by the Geomatics Division of CTTC [5]. The DAM consists in map of georeferenced points of measurements. Each point is characterized by an estimated annual velocity and its cumulative movement between each satellite acquisition. All the velocities and displacements are measured in the Line of Sight (LOS) direction of the satellite. The general noise level of the velocity map is assessed using the standard deviation of velocity values.

- The Active Deformation Areas (ADA) map has been generated using the ADA Finder tool [6-8], which makes a semi-automatic extraction from the DAM of the most significant active areas, based on the methodology described in [4]. An ADA is a grouping of at least 5 so-called "adjacent" points with a displacement velocity higher than a threshold. To determine whether two points are adjacent, the distance between them must be less than 2 times their radius of influence. Based on the full-resolution dimensions of pixel images, the radius of influence of the dots was set at 26 m. In MOMPA the velocity threshold to select the active points has been set to 3 times the standard deviation of the velocity map. For each ADA, the following parameters are resumed: the number of aggregate active points, the average, maximum and minimum values of velocities, and the average value of cumulative deformations within each ADA.

Thus, in the French area, CTTC provided a dataset with a selection of 299 ADA (figure 3). All of those areas have been analysed from the cross-checking of historical data, bibliographic data, analysis on google maps and searches in different databases (especially www.infoterre.fr) and drawing on the field knowledge of various CEREMA experts.

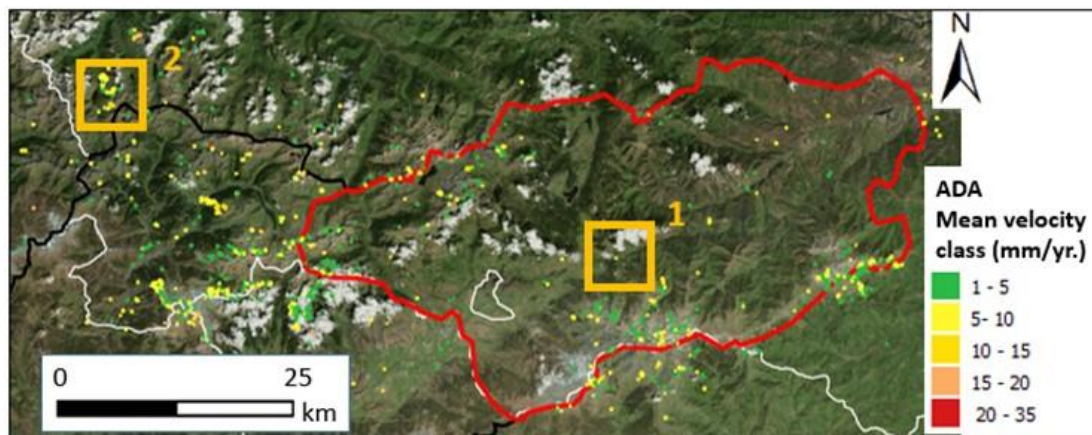


Figure 3. Identified ADA in the whole area in the French (surrounded in red) and Andorran areas of MOMPA. In the orange rectangles, the localization of the two active areas presented in the next part (1: Sauto-Le Pallat, 2: Soulcem).

4. Field analyses

Finally, 6 moving sites near local infrastructures were identified (figure 4) and 8 more in not urban areas. Field analyses of those 6 sites were realized in order to validate (or not validate) the reality of the detected moving areas. In this paper and as we cannot be exhaustive, we will focus only on Sauto and Soulcem (see their location in figure 3 or 4).

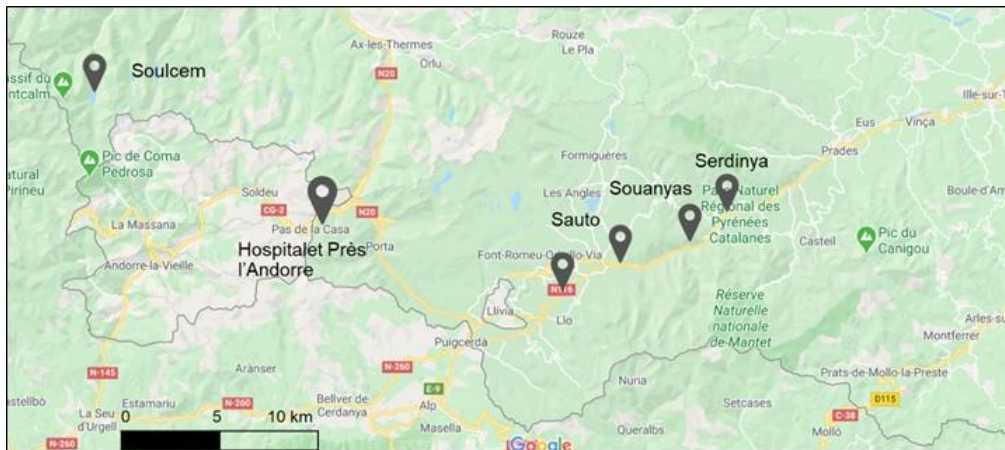


Figure 4. On-field studied sites.

4.1. Sauto – Le Pallat Landslide

Le Pallat landslide is located along the road RN 116, near Sauto village. This landslide is known since the 2000s, following the decision to expand the RN 116 to create an overtaking path. Numerous movements occurred during the roadworks (slides) which slowed their completion. Geotechnical studies have shown the role of the Canaveilles irrigation canal located upstream of the slope. The presence of white clay in the slide must have contributed to the destabilization of the slope in 2007 (figure 5). The mechanism of the landslide seems not to be a large one but rather several interlocking slides. Recently, following Gloria storm in January 2020, the road was kept closed again during nearly 3 months to performed drainage and reinforcement works.



Figure 5. Le Pallat - Sauto slope, before and after 2007 landslide.

The ADA located in the zone corresponds to a set of 11 points (figure 6) with LOS velocities between 3 and 10 mm/year.

The objective of the field study was to compare the active deformation areas detected by the InSAR method with the “real” active area. As it can be observed on the right of figure 6a, on the Pallat – Sauto site, the global stretch of the landslide (white dot line) is correct, but it is not located on the real area. The two area are offset by about 30 m.

We then try to find out if the “moving points” could refer to real moving points that would not be located in the already known landslide (white dot line on figure 6) but to a larger unknown one. On field, it seems that some of the moving points could correspond to large granite blocks located upstream a security net, but no signal of larger landslide was identified.

Finally, in this site, the InSAR technique seems to detect a movement that does not correspond to the main known landslide, which corresponded to a more vegetated area. The orientation of the landslide

slope with respect to the geometry of the satellite acquisition, together with the vegetation, are probably not optimum for the intrinsic limitation of the InSAR technique. Further processing at a local scale will be done to improve the data.

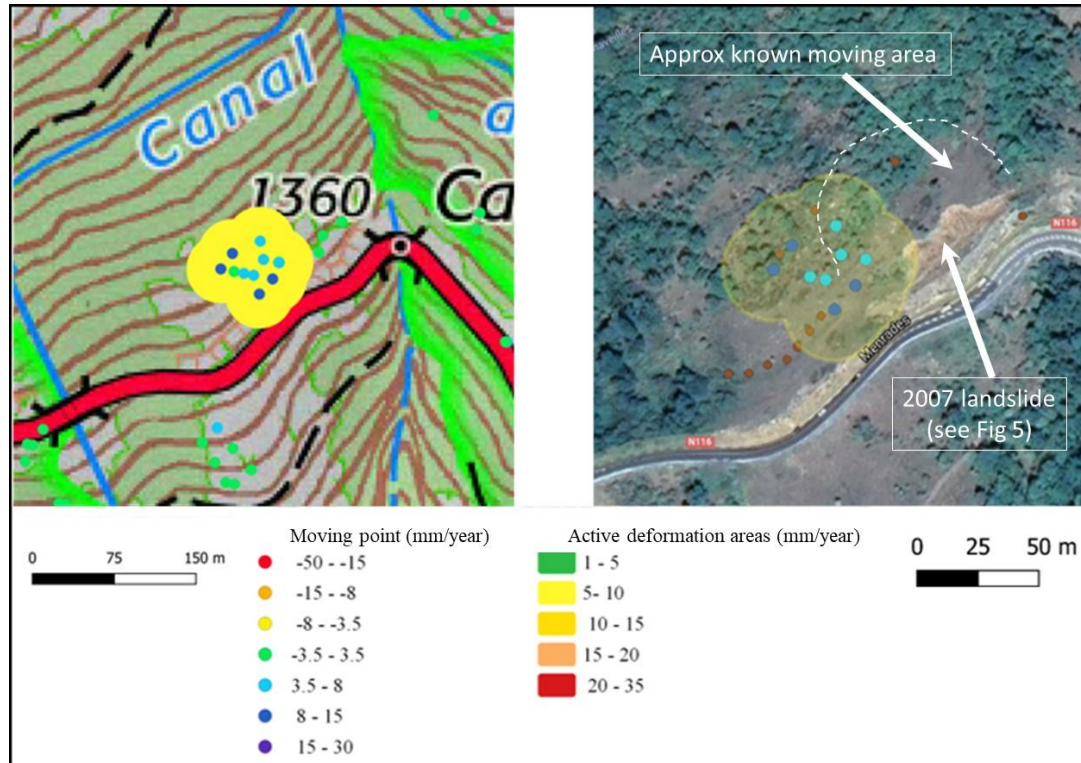


Figure 6. Moving points and ADAs in Sauto – Le Pallat site.

4.2. Picôt Landslide

This site under study is located downstream Soulcem hydroelectric dam on its right bank slope. In the area, the slopes are very steep and mainly composed by micaschist gneiss, injected with numerous veins of pegmatic granite, and with scree [9]. This rock, showing numerous glacial polishes, is cut by faults.

The remote sensing method applied on the area was able to identify a slow landslide on the right side of the bank and to track its evolution over the last four years. The ADA brings together a set of 3253 moving points with a speed of up to 23.4 mm/year (figure 7 and figure 8). Further on field analysis should be performed to better correlate the relative velocities.

In this case, field observations are more conclusive. Even if each moving point on ADA does not correspond to a “real” moving point, the global variation of velocities shaped on the slope seem to be reasonable even if we can’t explain yet the repartition of velocities. Later on, during the project we should work on available data on this site to validate the intensity of velocities.

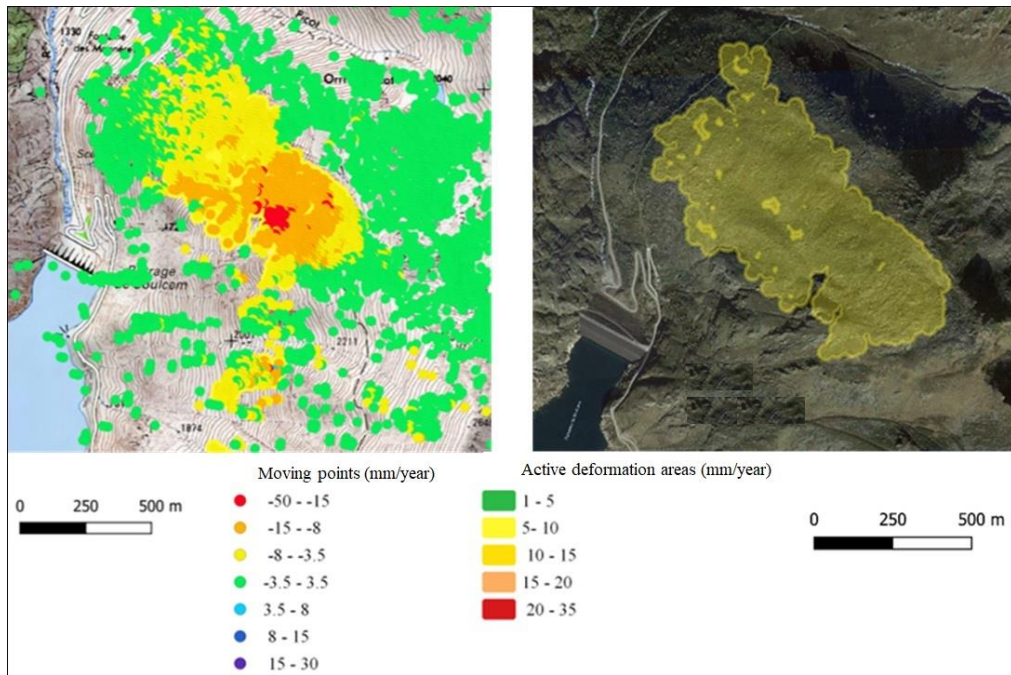


Figure 7. ADA on Picôt site – upper view.

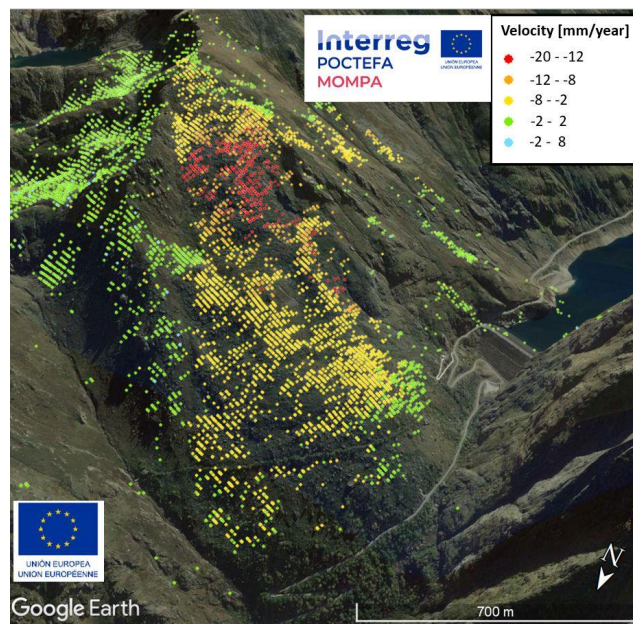


Figure 8. Velocities on the Picôt landslide shaped on google street view.

5. Conclusion and further works

The objective of MOMPA is to improve risk management, to contribute to evolve from a reactive approach to a proactive one. The innovation element of the project is applying the interferometric SAR (InSAR) technique, based on satellite imagery, for the enhancement of geological risk management. This technique, which is sensitive to small terrain deformations, can be used for an early detection of movements.

In the French area, satellites images processing gives a dataset with a selection of 1,635 ADAs. All those areas have been closely cross-checked and finally 6 sites have been chosen to be cross-checked by on-field analyses. Two of them were presented in this paper.

Work is still on progress, but the first results show encouraging results mainly on large areas.

Acknowledgments

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