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MOMPA: InSAR monitoring in the Eastern Pyrenees

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ABSTRACT

This paper describes the main outcomes of the European research project MOMPA (Monitoring of Ground Movements and Action Protocol). Its objective is to provide useful tools for the prevention and management of risks due to slope movements, based on the satellite monitoring InSAR (Interferometric SAR) technique. The project includes two parts: risk evaluation and the integration of InSAR in an action protocol for Civil Protections. The study area encompasses 4000 km^2 including a part of the eastern Pyrenees. The project exploited medium-resolution (Sentinel-1) and high-resolution (COSMO-SkyMed) satellite images to generate ground displacement maps at interregional scale and detect the Active Deformation Areas (ADA). The ADA map was used to select movements with potential risk which were further examined by a local analysis using photo interpretation and fieldwork.

I. Introduction

The MOMPA project (Monitoring of Ground Movements and Action Protocol) is co-financed by the European Regional Development Fund (ERDF) through the Interreg V-A Spain-France-Andorra Program (POCTEFA 2014-2020). MOMPA is part of Strategic Axis 2 of POCTEFA, "Promote adaptation to climate change and risk prevention and management", with the specific objective of "Improving the capacity of anticipation and response of the actors of the territory to the specific risks management of natural catastrophes". The project consortium is composed of four partners specialized in remote sensing, risk analysis and management techniques: the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Andorra Research + Innovation (AR+I), the Cartographic and Geological Institute of Catalonia (ICGC), and the Cente d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement (CEREMA). It counts as associate partners the civil protections of each territory and the company Euroconsult Andorra S.A. The main expected results of the project are the following: (i) monitoring maps of ground movements in an area included in the territories of l'Alt Urgell, Cerdanya, Capcir, Conflent and Andorra; (ii) associated risk assessment; and (iii) action protocols to support Civil Protections. The idea of the project is to have a pyramidal approach to risk management. From satellite interferometry (InSAR) based deformation maps (regional scale), the Active Deformation Areas (ADA) are detected and classified according to the associated potential risk level. Then, the classified ADAs allows focusing over the most critical ones, where a local and detailed study is carried out. The main technical work packages (actions) are:

- Action 3 - Monitoring of ground movements: generation of annual deformation velocity maps and deformation time series using medium (Sentinel-1) and high-resolution (COSMO-SkyMed) satellite imagery. Extraction of the detected ADAs.
- Action 4 - Risk analysis associated with ground movements: risk assessment of the exposed elements based on a delimitation of the geological phenomena associated with the ADAs detected in Action 3. Two analyzes are planned: the first will be based on deformation maps and deformation time series at medium resolution, the second will be based on the data at high resolution.
- Action 5 - Action protocol involves carrying out two main activities: the analysis of the pre-alert or alert thresholds of the analyzed movements, and the methodological development of the action protocols for Civil Protection.

The aim of this work is to present some results achieved in the Action 3.

II. Deformation monitoring

Action 3 focuses on the use of InSAR for ground movements monitoring. Its results are the main input data of Actions 4 and 5. The deformation monitoring is based on the InSAR technique, which uses a series of SAR images acquired over the same area. The technique works well on urban areas, infrastructures, rocky areas, etc., while usually obtaining few measurements (or none at all) over vegetated areas (Hanssen, 2005; Berardino *et al*., 2002; Barra *et al*., 2016; Crosetto *et al*., 2016). In Action 3 the deformation estimation has been made using the PSIG software of CTTC, using a processing tailored to the study area. For more details see Devanthéry *et al*. (2014). It is worth underlining that all the estimated deformations are in the Line of Sight (LOS) of the satellite.

The first processing has been based on medium-resolution (4 by 14 m) Sentinel-1 images in descending geometry. The entire MOMPA area of interest fits within the frame of a single image (see Figure 1). The interferograms have been generated from six bursts (sub-images) and two swaths. A total of 203 images have been processed that cover the period from July 4, 2015, to December 28, 2020. The images typically have a time gap of 6 or 12 days. However, several images of the winter periods (from December-May) have been removed to avoid problems due to snow cover (Solari *et al*., 2020a; 2020b; Mirmazloumi *et al*., 2021). Using this data, a velocity map over the entire study area has been generated (Figure 2).

From the velocity map, the ADAs have been extracted using the ADAFinder tool (Barra *et al*., 2017; Tomas *et al*., 2019; Navarro *et al*., 2020). An ADA is extracted as a polygon if there are at least 5 adjacent measurement points that have a velocity greater than two times the standard deviation of the velocity map ($2\sigma = 3.5$ mm/year). The ADA map facilitate the interpretation and use of the InSAR products, helping to focus the analysis on the areas of deformation. Thanks to the ADA detection, areas of greatest interest have been selected due to their potential risk. Over these areas, locally, the deformation time series have been generated with the method of Devanthéry *et al*. (2014). Other methods are described in Ferretti *et al*. (2000; 2001).

A second processing has been based on high-resolution data (3 by 3 m) acquired by the COSMO-SkyMED satellites in Stripmap acquisition mode, with descending geometry. The frame of these images is marked in yellow in Figure 1. It covers Andorra and the northern part of Alt Urgell. For the first high-resolution results, 36 available images covering the period between July 2013 and July 2020 have been processed. A map of annual deformation velocity covering the main urban centers has been generated, see Figure 3.

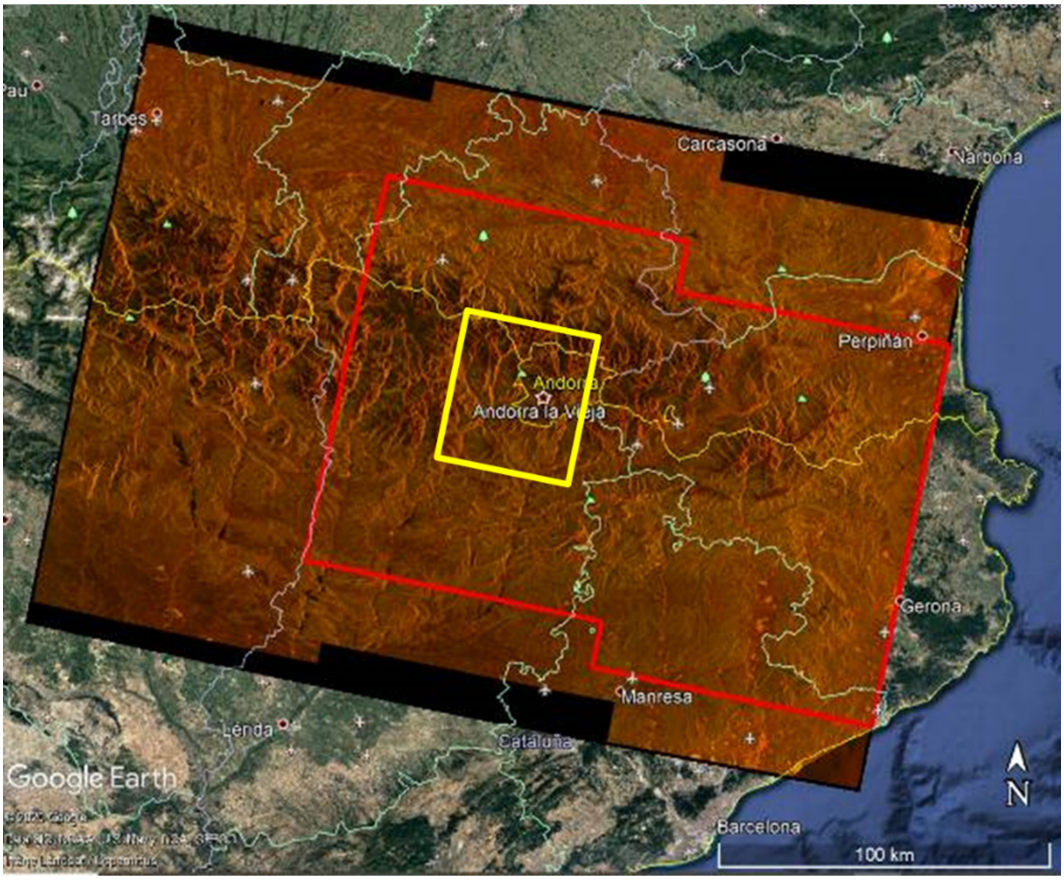

Figure 1. Extent of the Sentinel-1 images is shown in brown. The red polygon indicates the part of the processed image. The yellow polygon indicates the extent of the COSMO-SkyMed images. Google Earth is the background image.

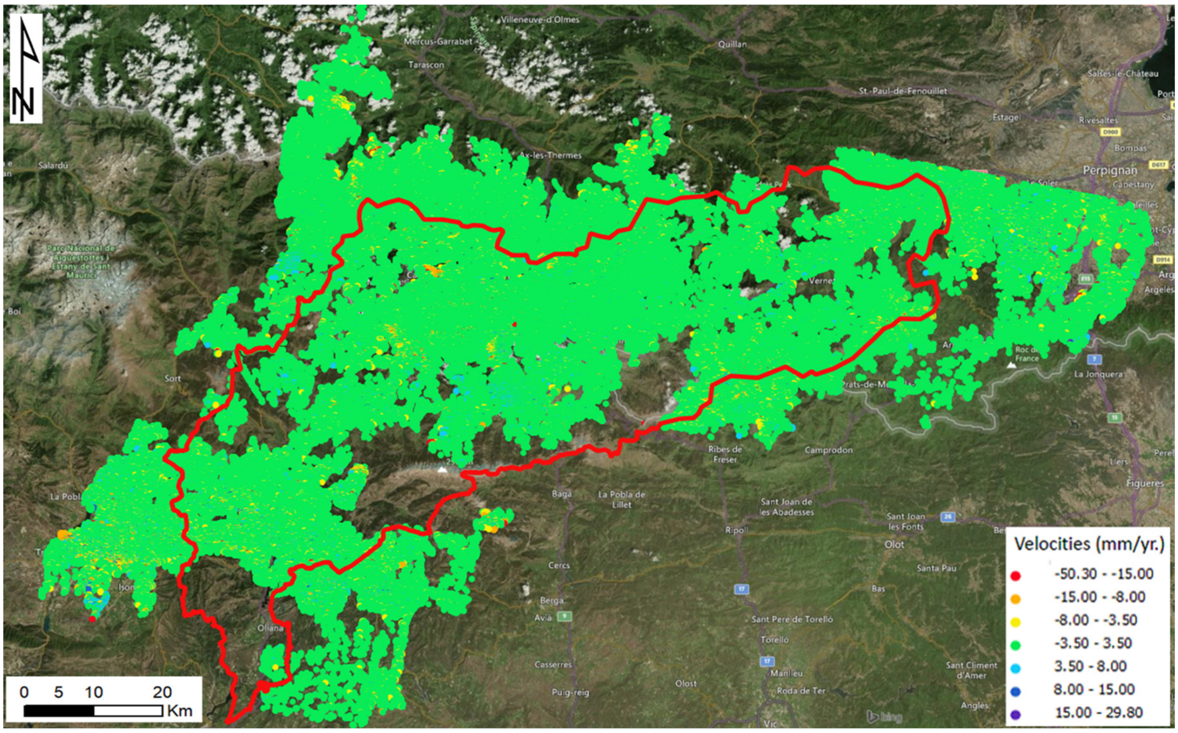

Figure 2. Map of deformation velocity (in mm/year) estimated using Sentinel-1 medium-resolution data. The map includes 2.904.322 measurement points. In red is delimited the area of study of MOMPA.

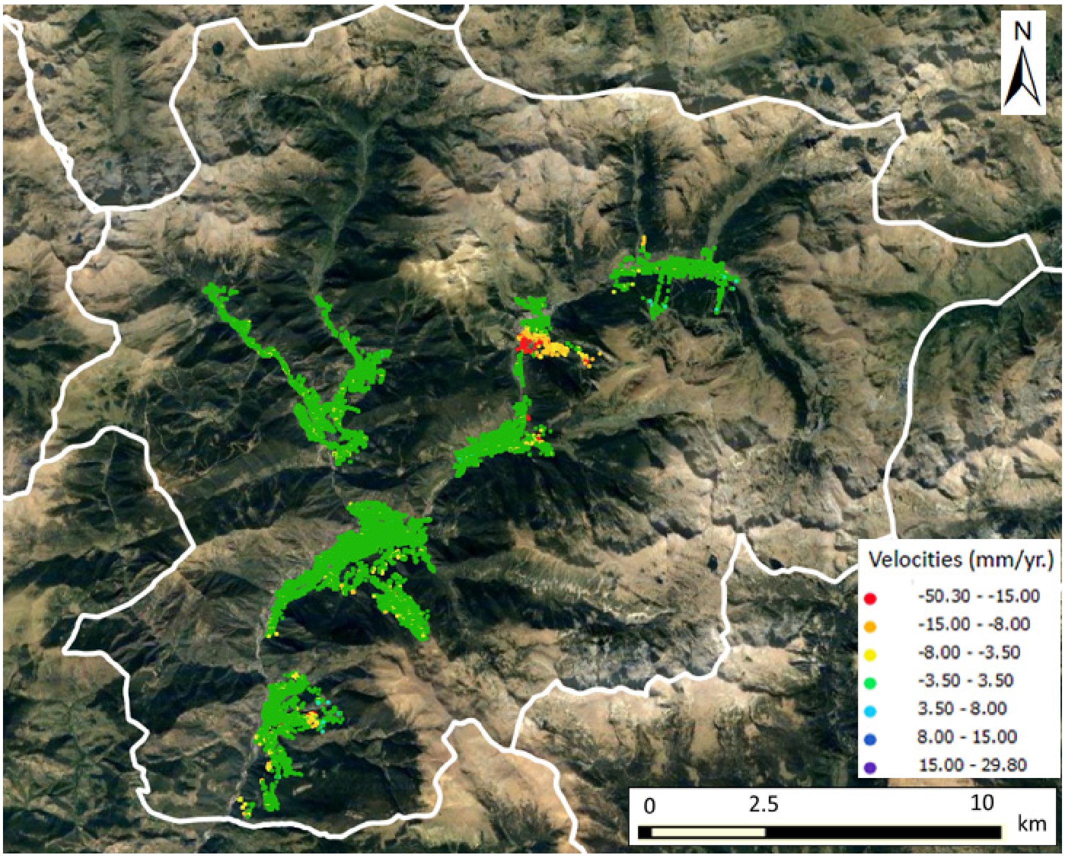

Figure 3. Map of deformation velocity (in mm/year) estimated using COSMO-SkyMed high-resolution data. The map covers the main urban areas of Andorra. White lines represent administrative limits (here the limit of Andorra).

III. Discussion of the Results

In this project we have experienced the power of a wide-area monitoring. In fact, this monitoring based on Sentinel-1 data has detected many interesting deformation phenomena. An example of landslide detected in a mountain area that includes a dam and a reservoir is shown in Figure 4. The upper left image of Figure 4 shows the deformation velocity map where several deformation areas were detected. The corresponding ADAs are illustrated in the upper right image of the same Figure. Finally, the lower image of Figure 4 shows a 3D view of the area using the color-coded deformation velocity values.

As mentioned above, the project involves deformation monitoring using X-band SAR data. Compared to the medium-resolution data, the high-resolution COSMO-SkyMed data offer very detailed deformation measurement results (Wegmüller *et al.*, 2010). With them, it is possible to follow the displacements of single localized features, see the examples in Figure 5.

It is interesting to compare the deformation results from Sentinel-1 and COSMO-SkyMed. Figure 6 shows an example of a localized landslide in Andorra, measured with both medium and high-resolution data. Both datasets describe very well the extent of the slide at hand.

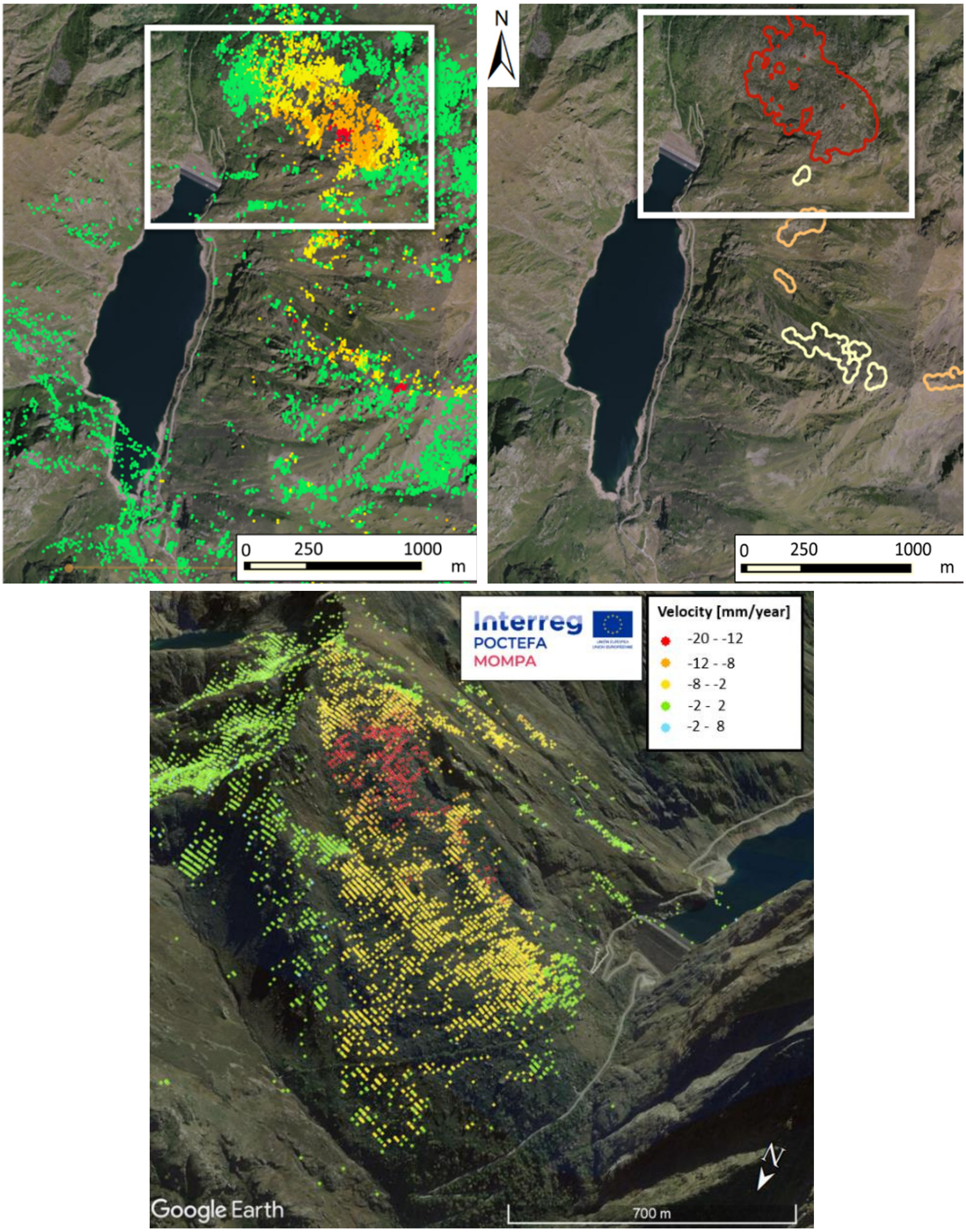

Figure 4. Example of monitoring result using the Sentinel-1 data. Deformation velocity map of an area that includes a dam (upper left). ADAs of the same area (upper right). 3D view of the area using the estimated velocities (lower image).

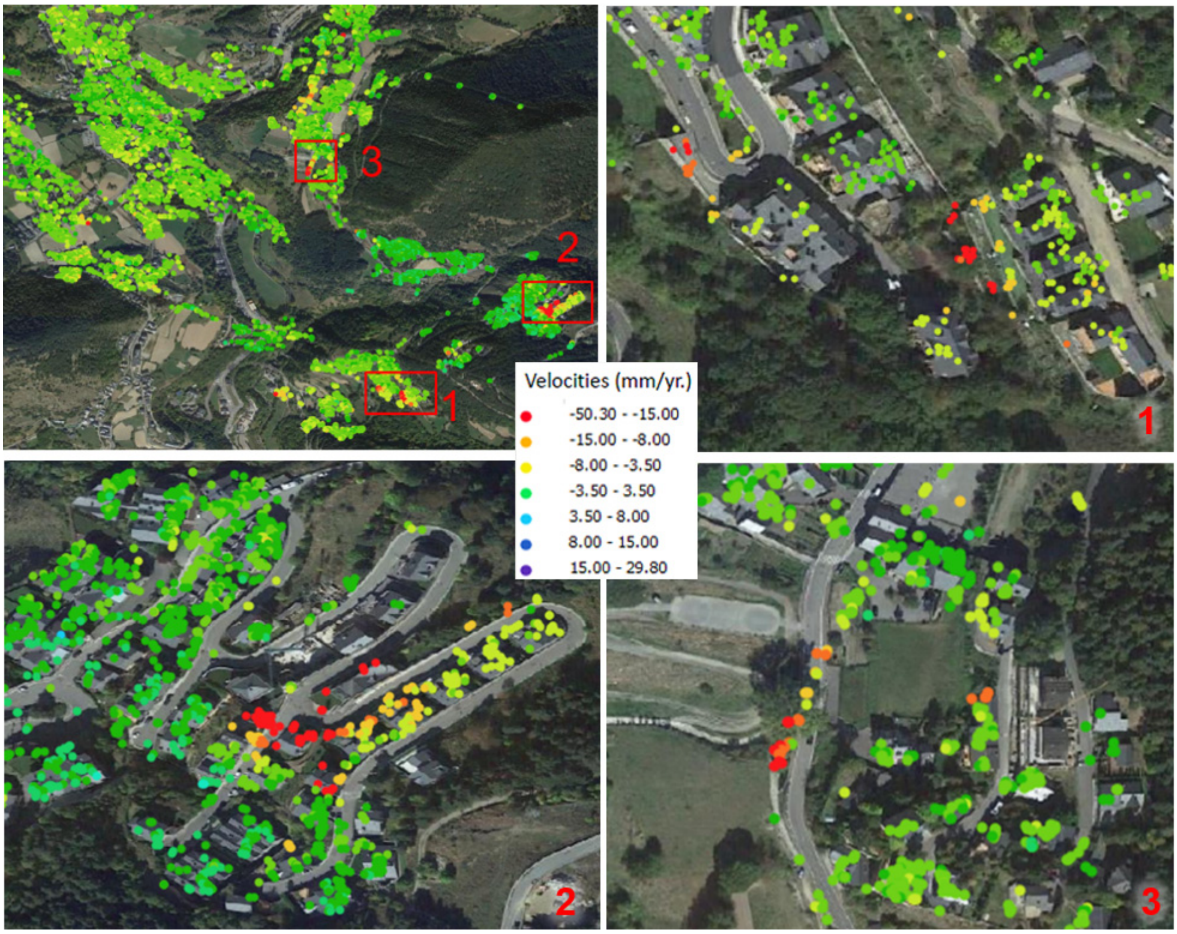

Figure 5. Example of deformation monitoring result using high-resolution COSMO-SkyMed data. Deformation velocity map of an urban area (above, left) and three zooms (area 1, upper right; area 2, lower left; area 3, lower right).

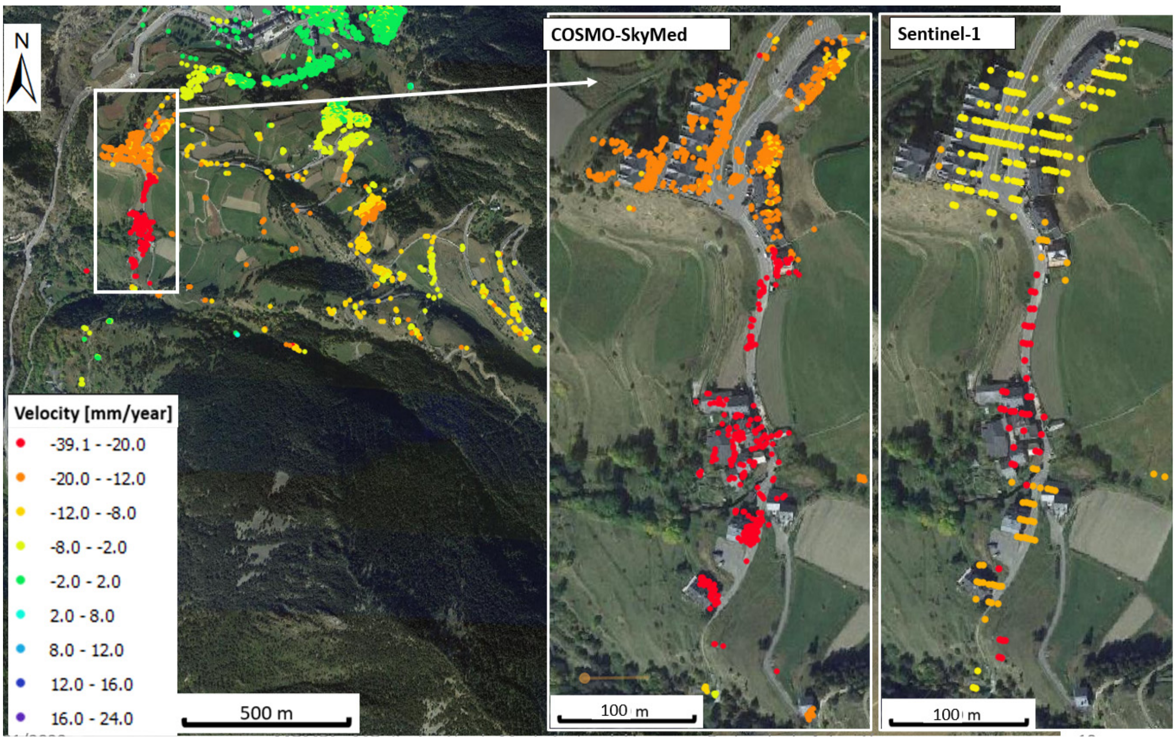

Figure 6. Comparison between Sentinel-1 and COSMO-SkyMed data over the same area, which includes a landslide. Deformation velocity map (left) and two zooms that show the measurement density of COSMO-SkyMed (centre) and Sentinel-1 (right).

Globally, Sentinel-1 offers a more complete and extensive coverage due to its greater coherence on vegetated areas. This is a clear advantage with respect to COSMO-SkyMed. On the other hand, observing the two zooms, it is evident how COSMO-SkyMed offers a very detailed sampling (approximately one point every 3 by 3 m), in correspondence with buildings, structures and infrastructures.

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