Gims

GEODETIC INTEGRATED MONITORING SYSTEM

FINAL PROJECT REPORT

INTRODUCTION

PROVIDING A COST-EFFECTIVE SYSTEM FOR THE MEASUREMENT OF MILLIMETRE GROUND MOTION BY MEANS OF GNSS, SAR AND ACCELEROMETERS

The main objective of the GIMS project is to build and commercialize an advanced low-cost system based on **EGNSS**, **Copernicus SAR** and other **in-situ sensors**, like inertial measurement units, for the purpose of monitoring **ground deformations** with a focus on landslides and subsidence.

The system will recover deformations with **millimetric level accuracies** and daily acquisition rate. Moreover, the integration of in-situ accelerometers will give real-time alerts in case of sudden movements. Finally, the low-cost infrastructure deployed for the landslide monitoring can be used as collector of environmental data for smart grids purposes.

The observations of these **three different monitoring techniques**, namely EGNSS, SAR and accelerometers, are complementary in time and space and can be **integrated** to obtain a better understanding of the monitored processes and a more complete knowledge of the deformation phenomenon.

The project involves **researchers** and **industrial developers** from different fields: radiofrequency analysis and related hardware design, telecommunications, SAR and GNSS data analysis, accelerometers signal processing, geostatistics, geology. Significant effort will be put in the **cooperation** between different areas and in the interface between different products and technologies.

The overall purpose of the **GIMS project** is to have detailed and timely knowledge of the **geophysical behavior** of parts of the Earth surface, and its hindrances on structures, in order to **mitigate** casualties and injuries to the population, and better plan maintenance intervention.

CONSORTIUM

INTEGRATION OF DIFFERENT COMPETENCES

GReD, Geomatics Research & Development srl (IT)
It's a SME, spin-off of Politecnico di Milano university, that studies, designs, and implements innovative and highly customized solutions based on geodesy and geomatic techniques. Besides being the coordinator of the project, it has developed an ad-hoc GNSS software able to exploit the new dual-frequency EGNSS receivers for geodetic monitoring, achieving millimeter-level precision.

Sviluppo Como – ComoNExT spa (IT)
CNXT, as an innovation-oriented science and technology park, supports the coordinator GReD in administration tasks and leads the dissemination and communications activities.

Saphyrion (CH)
Saphyrion designed and produced the GIMS stations, including the dual-frequency low-cost EGNSS receiver, a low-cost inclinometer, a low-cost IMU and all needed components (e.g. photovoltaic panels, batteries, modems, etc).

GeoNumerics (ES)
GeoNumerics developed the IMU analysis software component of the GIMS system.

Centre Tecnològic de Telecomunicacions de Catalunya (ES)
CTTC designed and developed a new low-cost active SAR transponder and enhanced their SAR processing tools for the estimation of land deformation maps.

Geoloski Zavod Slovenije (SI)
GeoZS brings to the project a direct user needs and evaluates practical capabilities and limitations of GIMS units by field implementation and validation of the data.

SITUATION AT THE START OF THE PROJECT

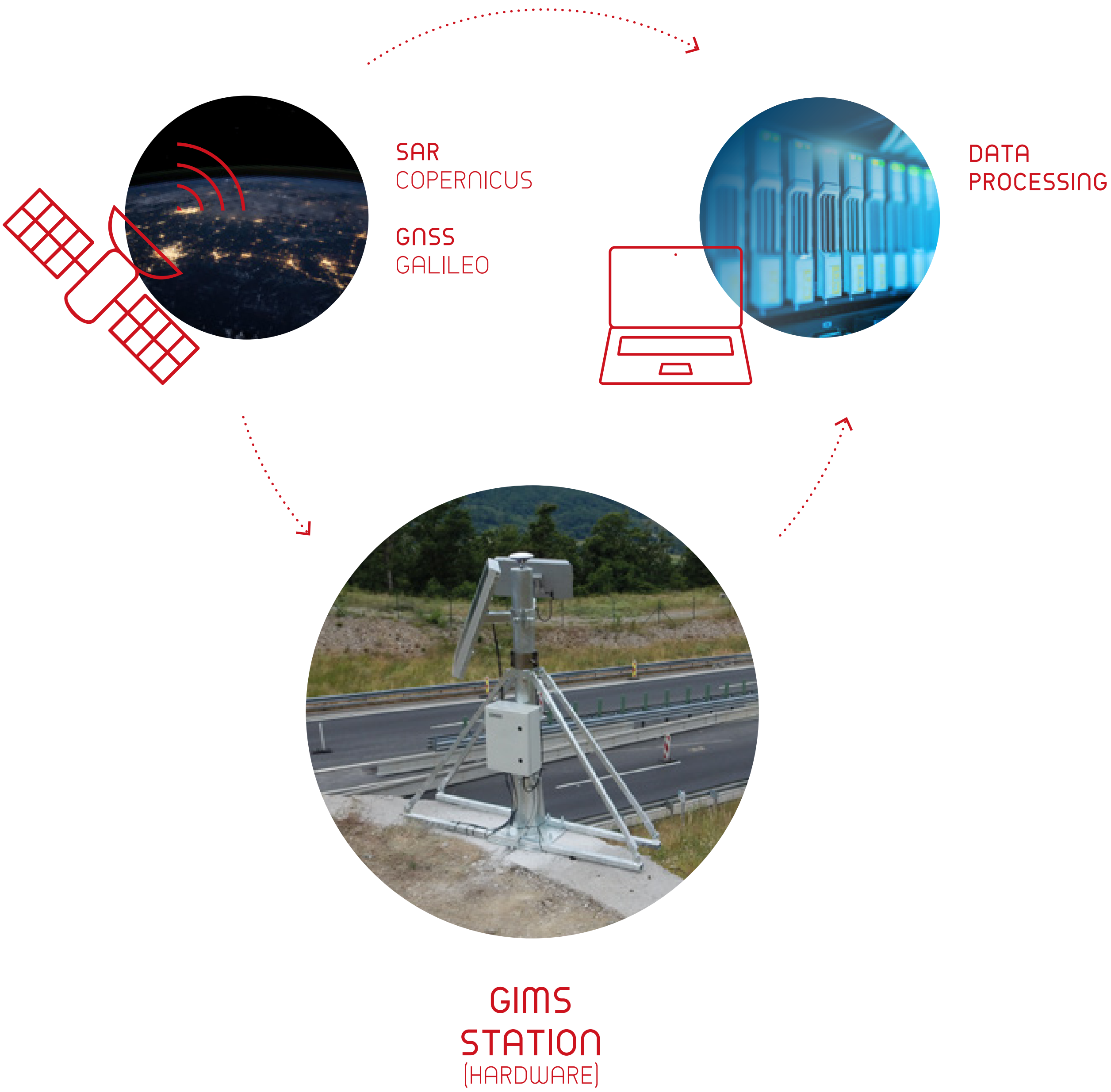
Geological, hydrological, geotechnical, and environmental phenomena causing deformation of the Earth surface (subsidence, landslides, floods, sinking, tectonic activity) are happening at an **increasing rate**, also due to extreme events likely to be driven by climate change, as well as rarer geophysical phenomena (earthquakes and volcanic eruptions).

These phenomena govern negative and sometimes **destructive impacts** on land, structures (dams, bridges, buildings), infrastructures (roads, railways, channels, pipelines, energy infrastructures, etc.), and ancient structures of artistic and cultural value (churches, ruins, archaeological sites, etc.); in addition, structures and infrastructures can undergo an obsolescence process, eventually leading to a **collapse**.

The sensitivity of many areas in Europe to different hazards as well as around the world, puts forward the **need** for an integrated and cost-effective **geodetic monitoring** capability.

THE GEODETIC INTEGRATED MONITORING SYSTEM – GIMS PROJECT

GIMS project aims at creating a deformation monitoring system for landslides and other hazardous movements of the ground that integrates cost-effective versions of costly technologies now used separately. Their **integration** allows to provide more comprehensive and more accurate results, which are an aggregation of images, movements and alarms.



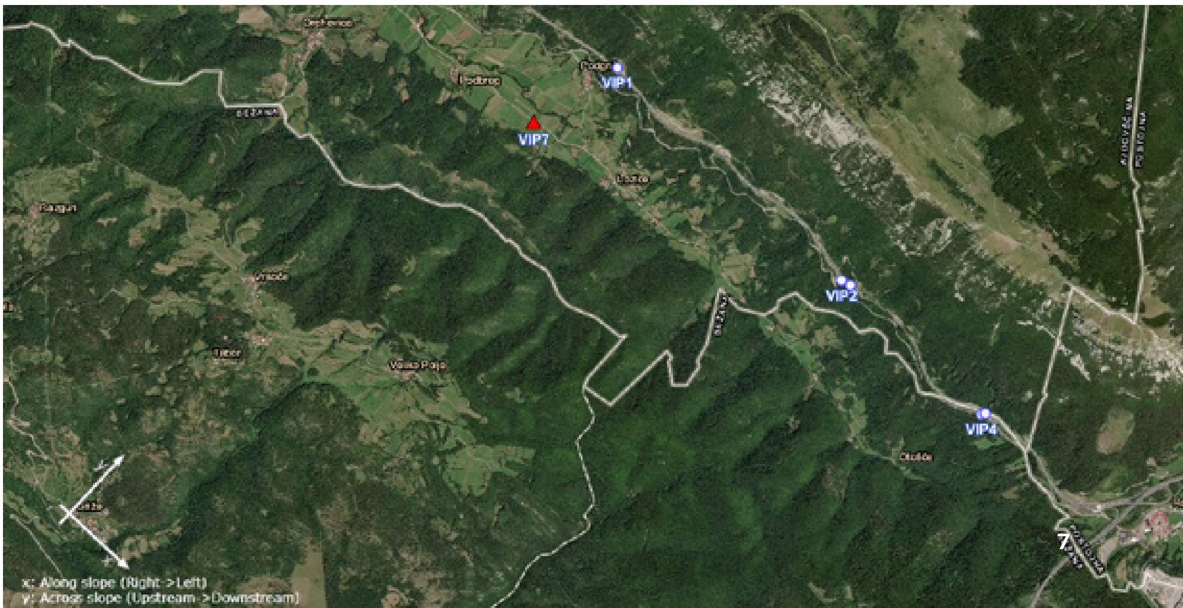
VIPAVA LANDSLIDE

GNSS + IMU

In the course of the project, fourteen GNSS stations have been installed in the **Vipava** and **Potoska** areas in Slovenia, on landslides and on a viaduct affected by them.

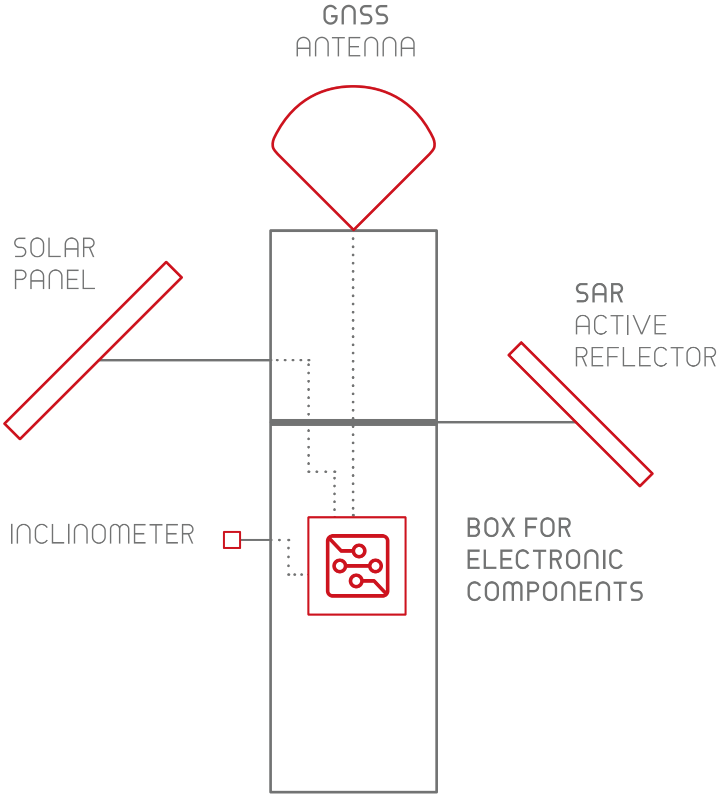
POTOSKA LANDSLIDE

GNSS + SAR + IMU



HARDWARE ON FIELD

The value proposition of GIMS is the ability to provide information about ground movement with a **high spatial and a temporal resolution**, by exploiting the strengths of the implemented surveying technologies, i.e. **GNSS** and **SAR**. Due to this fact and to the implementation of **accelerometers**, GIMS monitoring system is suitable to be used as an early warning system for landslide hazards.



GNSS

The Global Navigation Satellite System provides continuous measurements on given points collected by GNSS satellites (including Galileo).

SAR

The Copernicus Sentinel satellites, in their trajectory around the globe, periodically transmit radar data that – once processed – provide images of deformations. With an active SAR Reflector it is easier to detect specific points to be measured.

ACCELEROMETERS (IMU SENSORS)

Inertial sensors placed inside the box are used to raise alarms in case of sudden hazardous movements.

BOX FOR ELECTRONIC COMPONENTS

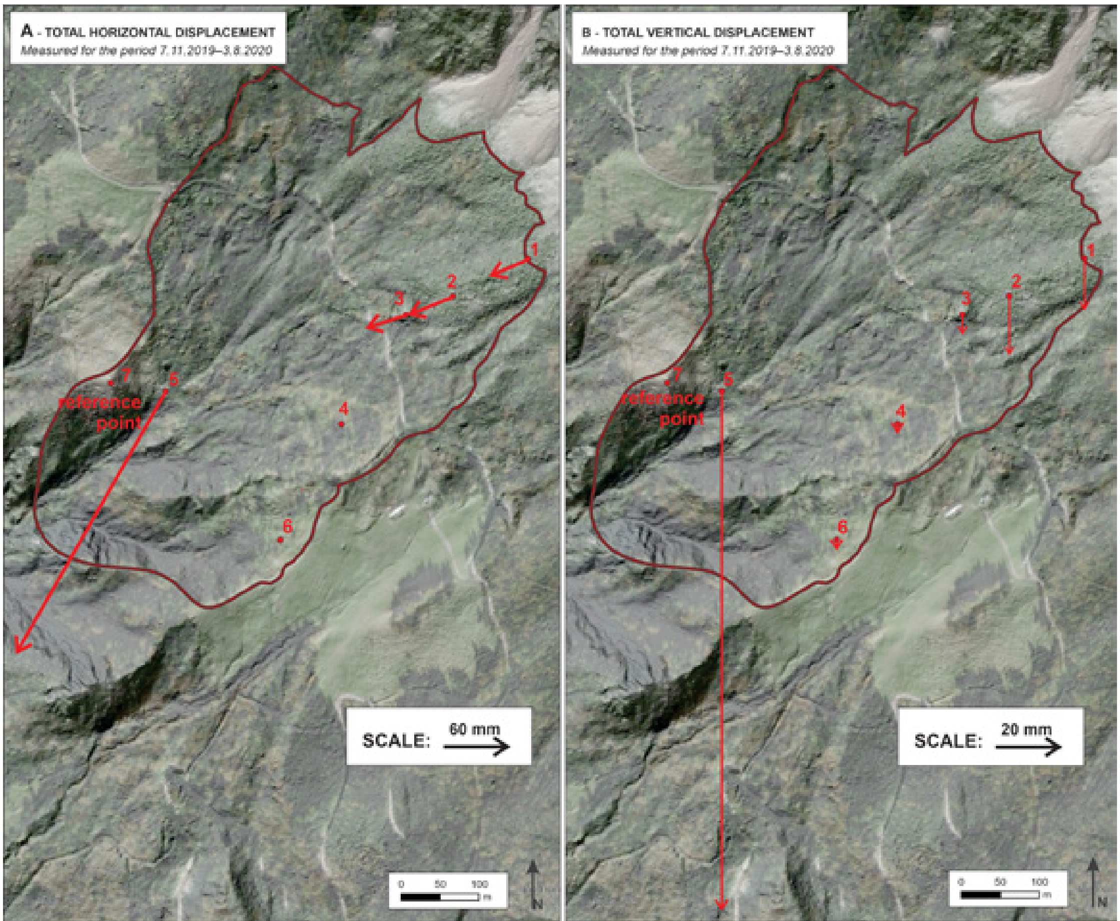
It contains a miniaturized computer that controls the three measuring technologies, collects data from them and transmits data to server. The solar panel powers the whole system. The Copernicus Sentinel SAR data are directly downloaded from ESA servers.

RESULTS

LOW-COST GNSS SYSTEM PERFORMANCES

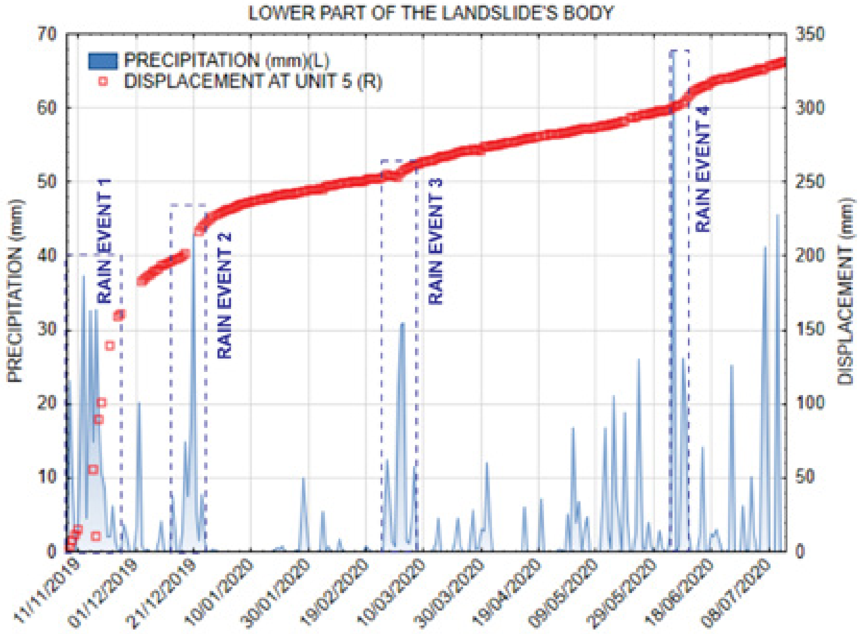
The **low-cost GNSS** units deployed in the Vipava and Potoska test areas were useful to detect the **undergoing movements** affecting the two landslides and their responses to external drivers.

For example, by looking to the maps below, the horizontal surface displacements in the upper part of the **Potoska landslide** ranged between 4 and 5 cm. During the monitoring period, the left flank of the landslide at the GNSS measuring points remained stable. The material in the funnel-shaped lower part of the landslide moved by app. 30 cm. The direction of the displacement followed the morphology of the terrain. The estimated annual horizontal surface displacements are close to **6 cm** for the **upper part** of the landslide and over **40 cm** for its **lower part**.



An interesting characteristic that can be detected thanks to the **low-cost GNSS** sensors is the direct correlation between **surface displacement and rainfall** (shown in the figure below). It indicates that for example the area around the unit 5 of the deep-seated landslide is dominated by shallow processes which quickly respond to **rain events**, as opposed to other parts of the landslide.

The time series of the data shows that the lowest part of the landslide is very **sensitive** to the amount and type of **precipitation** and constantly adapts the displacement to environmental conditions.



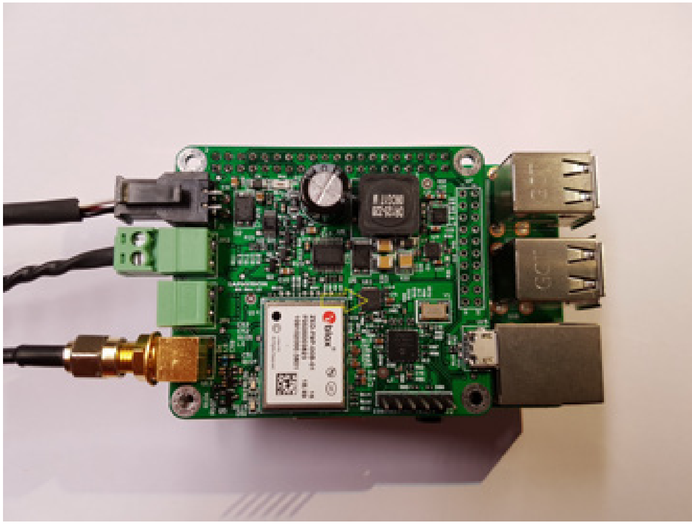
RESULTS

LOW-COST MEMS PERFORMANCES

IMU

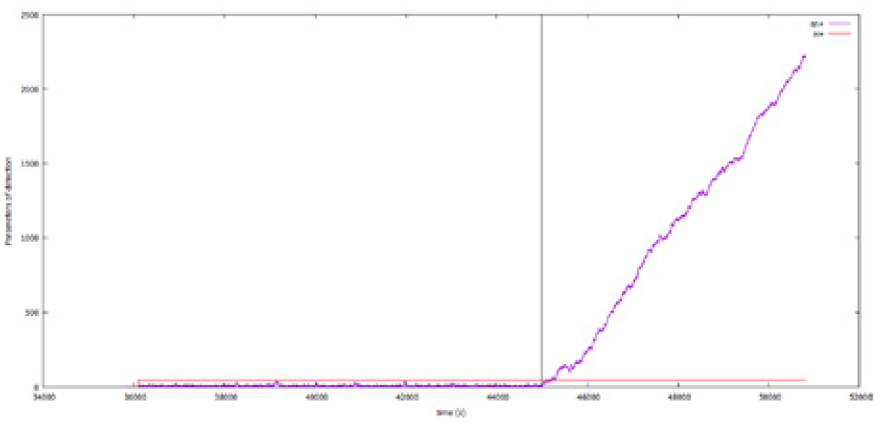
The **IMU sensor** has been embedded in the board entirely realized by Saphyrion SAGL, that acts also as management module of all the data streams collected by GIMS sensors.

The main driver of the IMU has been the **cost effectiveness** of the solution and thus the TDK InvenSense ICM-20689 IMU (3-axis accelerometer + 3-axis gyroscope) has been selected.



The result of this search is the identification of **sequential changepoint detection** (SCD) methods, mainly used in manufacturing statistical process monitoring (SPM) and control (SPC). These methods are based on algorithms usually known as "control charts". Among the family of **control charts** it has been selected the cumulative sum (CUSUM) one.

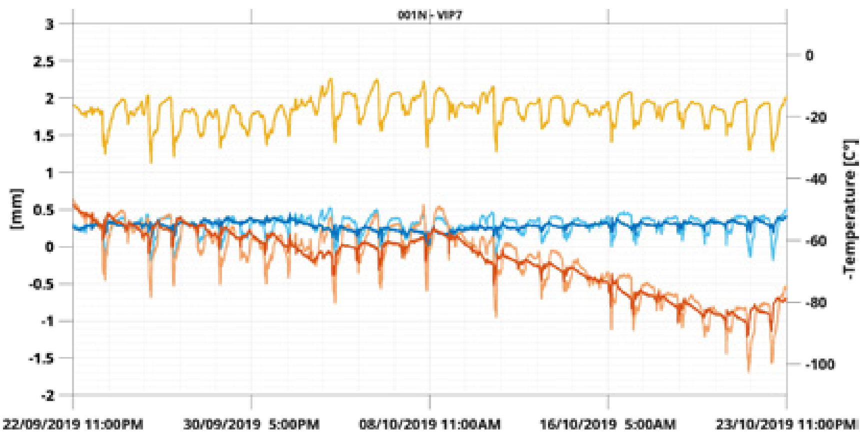
Figure below displays the **change detection statistics** as a function of time (magenta curve) against the detection threshold (red line) for an Analog Devices ADIS16495 IMU, which is a low-grade lightweight MEMS one.



INCLINOMETER

The **ZC ZCT215M inclinometer** (2-axis digital tilt sensor) has been tested during GIMS project.
This sensor is external with respect to the mother-board and has been attached to the same vertical pole holding the GNSS antenna, in order to detect **rotations of the pole**, and decouple them from the movements detected by GNSS.

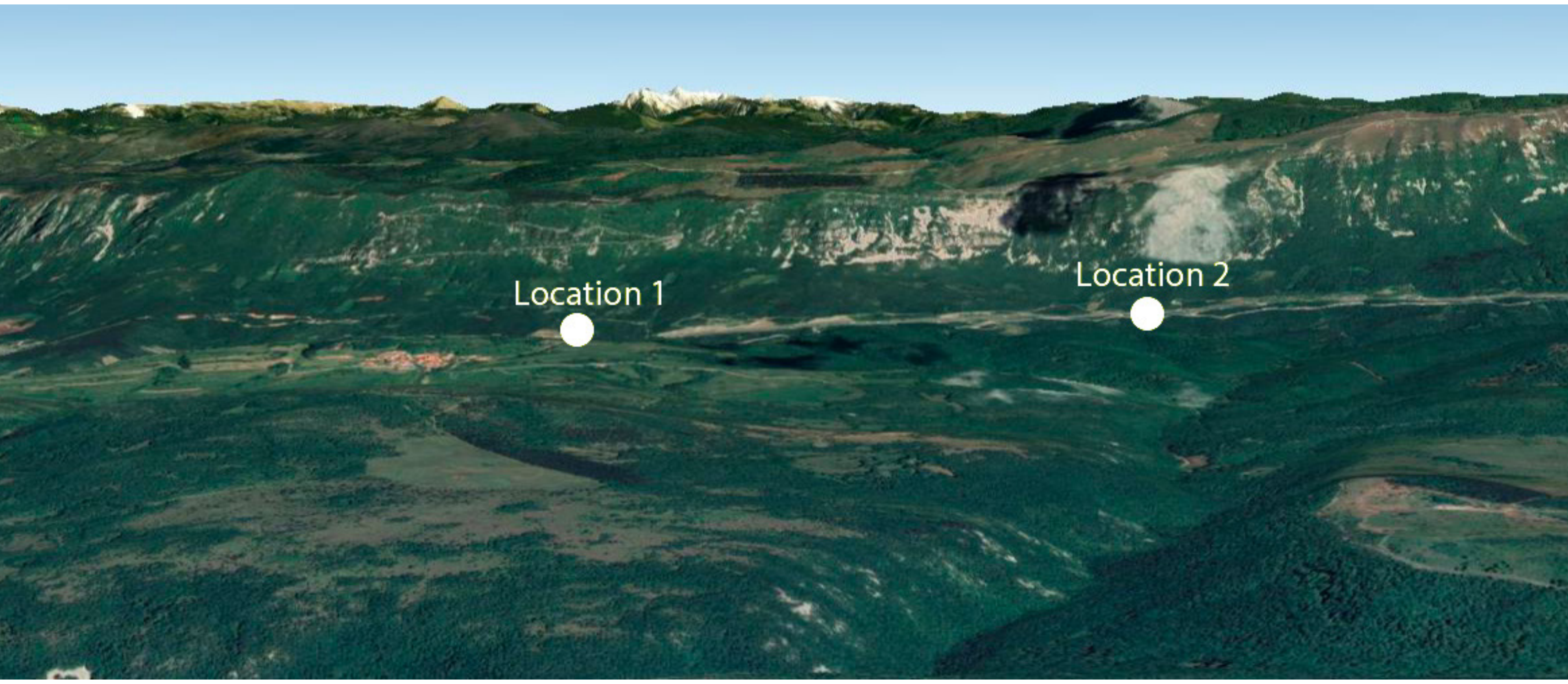
The procedure followed to process the GIMS inclinometer raw data firstly relies on a **high frequency filter** of the recorded signal and then a decorrelation from temperature.
In this way, GIMS inclinometer data were particularly useful as an **ancillary tool to evaluate GNSS displacements**, e.g. ruling out a suspected pole rotation for the large displacement detected by the station POT5 at the Potoska site.
Example of **temperature decorrelation** of GIMS inclinometer data is reported in the bottom figure (light blue/red: uncorrected data; dark blue/red: corrected data).



RESULTS

ACTIVE SAR REFLECTOMETER PERFORMANCES

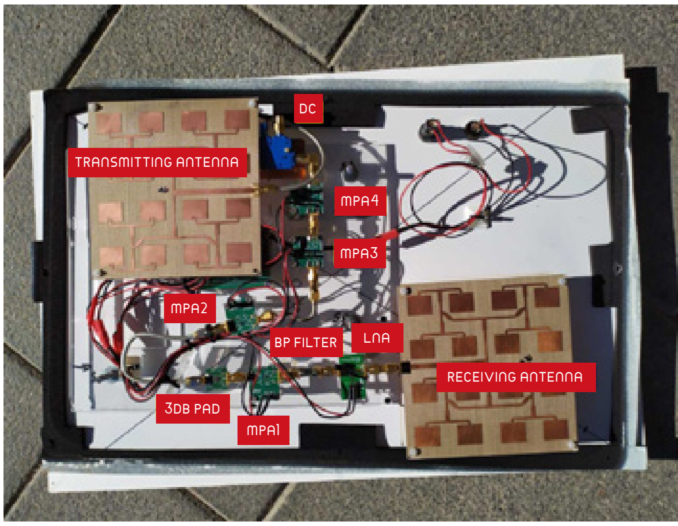
Within the GIMS project, the main SAR analysis has been performed on the Vipava test area. **Two ACR prototypes** were installed in the Vipava valley itself.

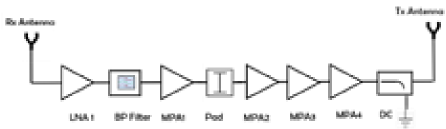


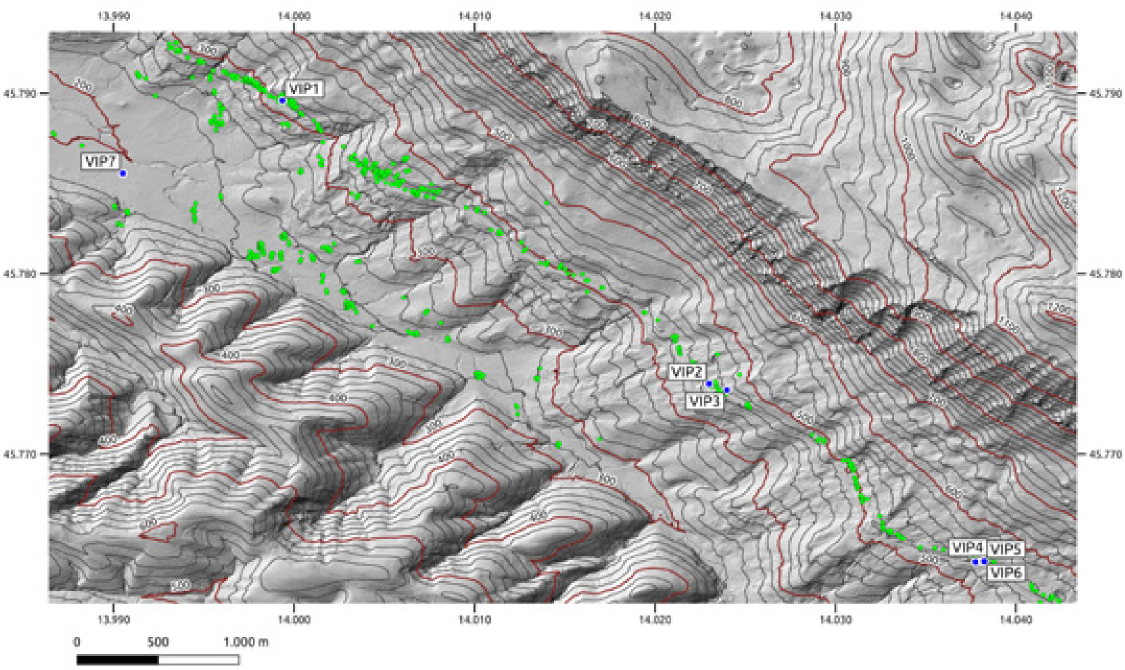
The installation was performed on 17, 18 and 19 June 2019 and the two active reflectors were installed in Location 1 and 2.

The map below clearly shows the position of the SAR PS (green) and GNSS receivers (blue). Because the area of interest is a valley, the **spatial distribution of the PS scatters** and receiver stations is **not optimal** for a spatial analysis.

In fact, both the GNSS baselines and the persistent scatters are mostly **parallel to the valley**. Furthermore, the height of the valley increase going from the top left to the bottom right.
This makes **difficult to distinguish** between **height dependent component** of the delay with its **spatial variation**.







Despite the difficulties, the design and implementation, after several tests and improvements of the **reflector sections**, was finally successful: the first **goal** to provide an adequate **Radar Cross Section has been achieved** with a circuit based on low costs reflector components.

Regarding the **phase stability**, the **results** obtained with an empirical approach, i.e. observing the behaviour directly on the field, are **promising**. The dispersion of the phase in terms of displacements was estimated to have a standard deviation of 2.73 mm and 2.42 mm, respectively.

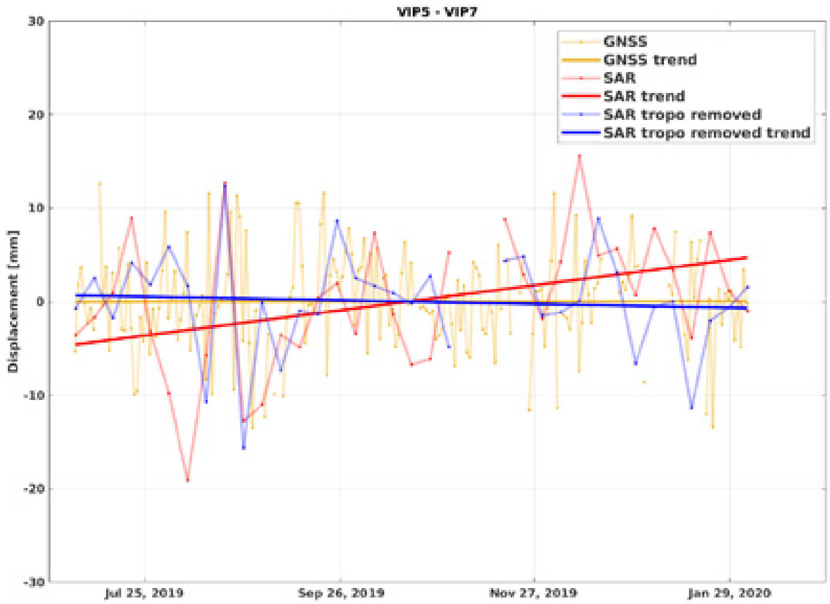
RESULTS

INSTRUMENTS INTEGRATION

It is evident that the **three involved technologies** have very different measurement resolutions in time and space, and that they have **strongly complementary capabilities: MEMS IMU** can target the identification of sudden movements (and this information can be part of an early warning / alarm system), **GNSS stations** allow to identify pointwise shifts at the level of about 1 mm per day or few mm per hour, and **SAR interferometry** allows for the identification of area deformations at level of a few millimeters with a latency of few days.
The **combined usage** of these three technologies is thus expected to give a **complete picture** at all the required spatial and temporal scales.

While this synergy between GNSS, SAR and IMU was already being explored by other research groups already at the time of the GIMS proposal writing, the main and most difficult challenge tackled by the **GIMS consortium** was to explore each technology capabilities and their combined **synergies** by using exclusively "**low-cost**" **instrumentation**, where "low-cost" refers to their cost comparison with respect to their high-grade counterparts.
For the GNSS component, competitors do not have a service included in the hardware sold.
GIMS allows to give a **complete product** (hardware plus service) with more than **50% reduction of the price**. Concerning the **SAR component**, the GIMS SAR service guarantees at least a **price 20-30%** lower than what is on the market.

The **GNSS-based correction improves the SAR results** for all baselines apart from VIP1-VIP7 and VIP2-VIP7. This is likely due to a combination of weak tropospheric signal over the shorter baselines (in this case, shorter than about 3 km) and a small movement trend. For longer baselines, and consequently stronger tropospheric signals, the longer the baseline is, the better the correction is expected to perform.
The Figure below shows a comparison between movement trends detected by SAR without GNSS correction (red), SAR with GNSS correction (blue) and GNSS (yellow): after the **tropospheric correction procedure**, the SAR trend become similar to the GNSS one.



The **experimental results** obtained predicting ZTD values from GNSS to SAR, even using very short baselines, can be considered **positive**, representing an innovative approach when dealing with GNSS and SAR ZTD predictions.
Further experiments are planned to be conducted at sites allowing for a more homogeneous spatial distribution of GNSS stations, and at various spatial scales.

PARTICIPATION

COMMUNICATION AND DISSEMINATION ACTIVITIES

During the whole implementation of the project, several **activities** were carried on in order to make the project known by the scientific community, companies and other relevant stakeholders.

1
RADIO INTERVIEW @RADIO24

27
CONFERENCES ATTENDED

8
MEETINGS WITH POTENTIAL CLIENTS

1
FAIR ATTENDED IN 2019

ALL TRADE FAIRS IN THE SECTOR WERE CANCELED DURING 2020 BECAUSE OF COVID

SOCIAL MEDIA ACTIVE

5
EVENTS ORGANIZED

3 EDUCATIONAL EVENTS
1 MID-TERM EVENT
1 FINAL EVENT

PRESS AND MEDIA COVERAGE FOR THE FINAL EVENT

TAILORED DISSEMINATION MATERIAL

WEBSITE
BROCHURE
INFOGRAPHIC
VIDEO ON DEPLOYMENT

17
ARTICLES PUBLISHED

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MORE INFORMATION AT:

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