The LASUGEO project: monitoring LAnd SUbsidence caused by Groundwater exploitation through gEOdetic measurements.

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Abstract

- PS-InSAR (Interferometric Synthetic Aperture Radar) data allow measuring slow-moving ground deformations with high spatial resolution.
- In Belgium, most of the subsidence is related to fluctuations of water pressure in aquifers (Figure 1) (Declercq et al., 2017; 2021).
- Any change in pore pressure (or piezometric heads) may induce consolidation if the geological formations are compressible. When groundwater levels and water pressures are restored, a partial rebound (uplift) corresponds to the elastic part of the geomechanical behaviour.
- The most sensitive layers contain clay, loam, or peat, ➔ consolidation occurs mostly in the underlying and overlying layers that are often less permeable and more compressible than the aquifer itself. Subsidence is a delayed process occurring as far as the pore pressure variation propagates slowly in the low permeability (aquitard) layers.
- The last 30 years PS-InSAR data measures the subsidence or uplift over large-scale areas, that we compare with hydrogeological groundwater and geomechanical models and other geodetic techniques (GPS/GNSS stations, absolute gravimetry).
- Targets ➔ he deep aquifer system of western Flanders, the Tertiary aquifer system in Central Flanders, the Antwerp area, the Leuven area, and the Brussels Region.
- The vertical land movements will be compared with 1D geomechanical model results. The latter will be performed using geotechnical effective stresses as deduced from the pore pressure distribution from the 3D hydrogeological models (Dassargues et al., 1989, Dassargues 2018).

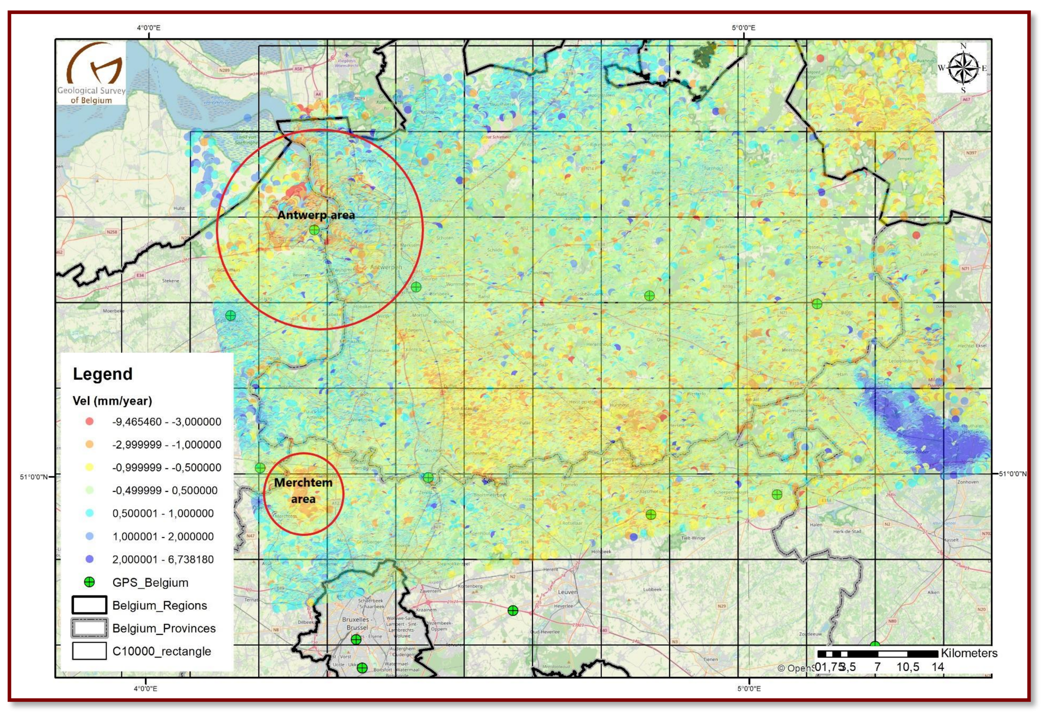
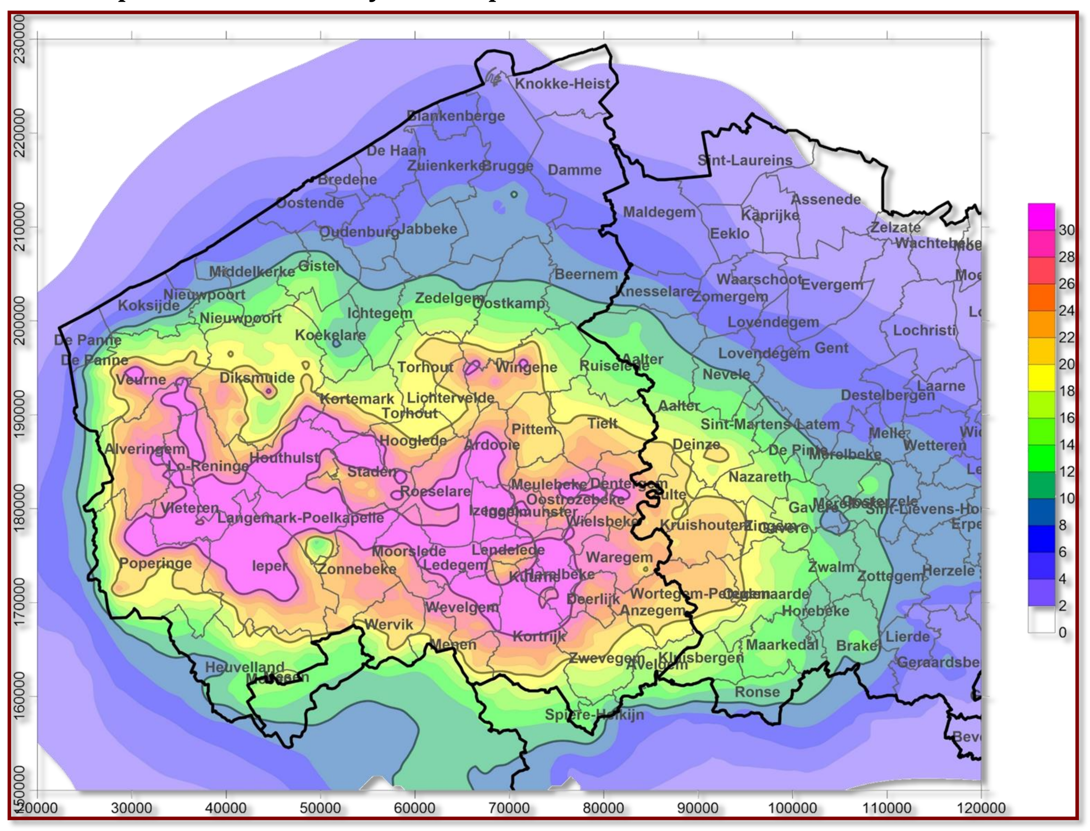


Figure 1. Sentinel1-A ascending LOS velocities across part of Belgium showing two main subsidence bowls (in the Merchtem and Antwerp areas)

Land Subsidence Simulation in Merchtem and the SW part of Flanders

Land subsidence is calculated by accumulating the compaction of all layers. The MODFLOW simulator was used as groundwater flow model and the 'Subsidence and Aquifer-System Compaction' (SUB) Package was selected for computation of the layer compaction & subsidence.



In the SW of Flanders, between 1920 & 2005, an intensive exploitation of the deep aquifer system (DAS), in the Paleozoic basement and Landenian Formation, has created a regional scale depression cone in the piezometric levels with maximum drawdowns up to 150 m in the basement aquifer and ~100 m in the Landenian Formation. Since 2005 pumping has been restricted but recovery goes very slow because of the limited recharge of these deep layers and even recently the remaining depressions cones are very deep. Simulating of the exploitation history of the DAS and calculating compaction and subsidence shows that subsidence reaches up to 3 cm in a 50 km-wide EW oriented strip (Figure 2).

Figure 2. Calculated land subsidence (in mm) in the year 2000 caused by the exploitation of the deep aquifer system (Paleozoic basement and Landenian aquifers).

In the Flemish-Brabant province, around Merchtem and Steenokkerzeel, known for its breweries, groundwater exploitation in the Ledo-Paniselian and Ypresian aquifers, but the depression that comes in these layers are local and limited, only a few meters deep. This is insufficient to create significant subsidence, even after a decade of pumping, as the model shows (Figure 3). Land subsidence is less than a cm.

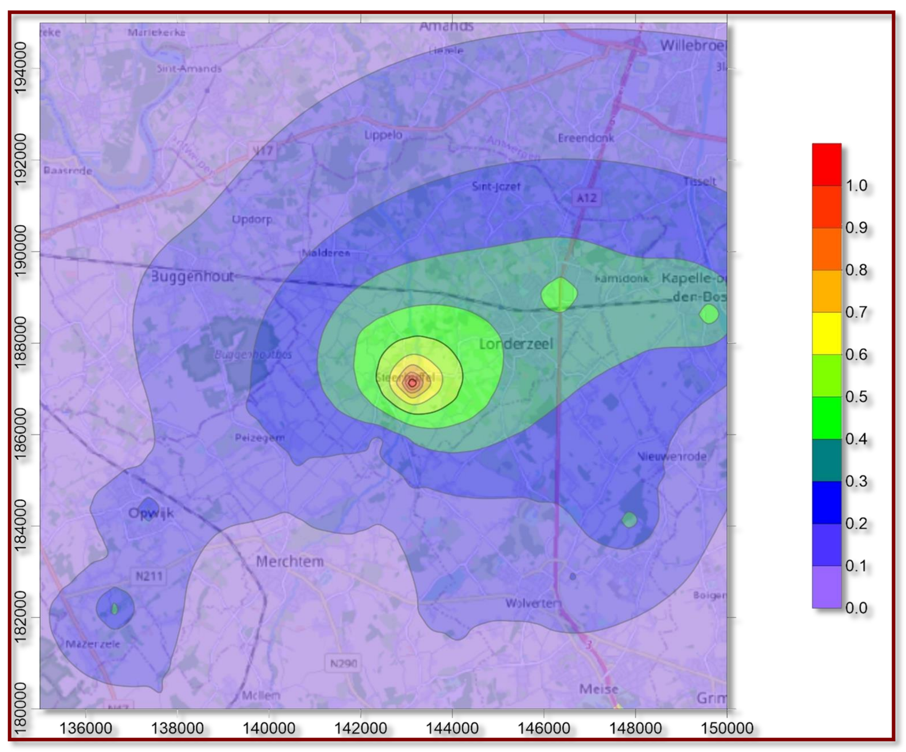


Figure 3. Calculated land subsidence (in mm) in the region around Merchtem and Steenokkerzeel due to pumping in the Ledo-Paniselian and Ypresian aquifer systems (situation after 10 years of pumping at the recent pumping rates).

Subsidence in Antwerp area

In Antwerp, four subsidence processes may occur:

1. Natural compaction of recent Holocene Formation
2. Additional settlement of recent Holocene due to backfill overburden along the new docks
3. Saturated-unsaturated consolidation of the backfill material itself
4. Compaction of the most compressible layers, probably in the Boom Formation (Paleocene) and in the Asse clay of the Maldegem Formation (Eocene) due to pore pressure decrease caused by groundwater pumping in the different Cenozoic aquifers.

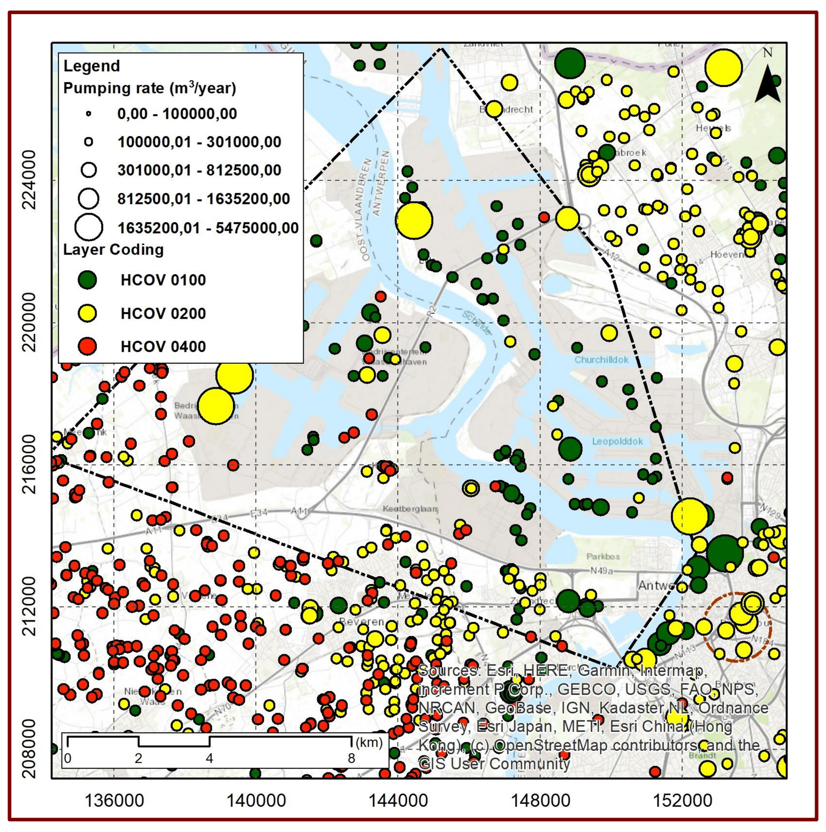


Figure 4. Distribution map of pumping wells over the study area.

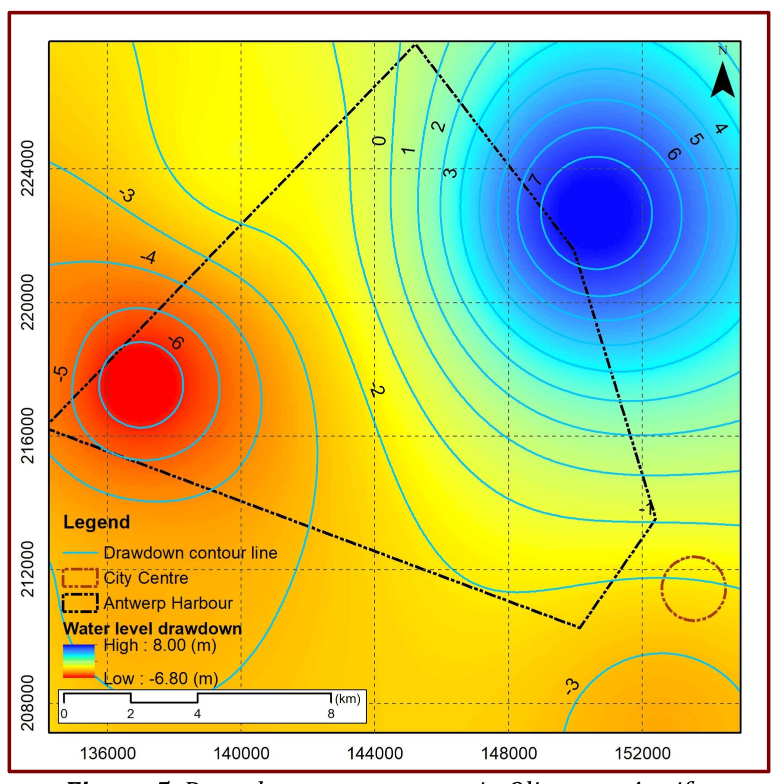


Figure 5. Drawdown contour map in Oligocene Aquifer during the period 2009-2017.

- at least two different zones with dissimilar behaviours: city centre and harbour of Antwerp
- differences in land subsidence rates in different zones of the area are linked to dissimilarity in the stability of subsoil
- effect of pumping groundwater from deeper layers particularly Oligocene aquifer, which can play an important role in the displacements of the region (Figure 4 and 5)
- groundwater model + 1D geomechanical model will bring comprehensive knowledge related to the subsidence processes going on in the area.

Groundwater Modelling in Leuven Area

In Belgium, most of the identified subsidence areas could be related to piezometric fluctuations in aquifers. Using PS-InSAR data, two areas of significant subsidence are observed in the north of Leuven. In these specific locations, many historical and currently active pumping wells are present. The most important pumping wells are screened in the Brussels Formation.

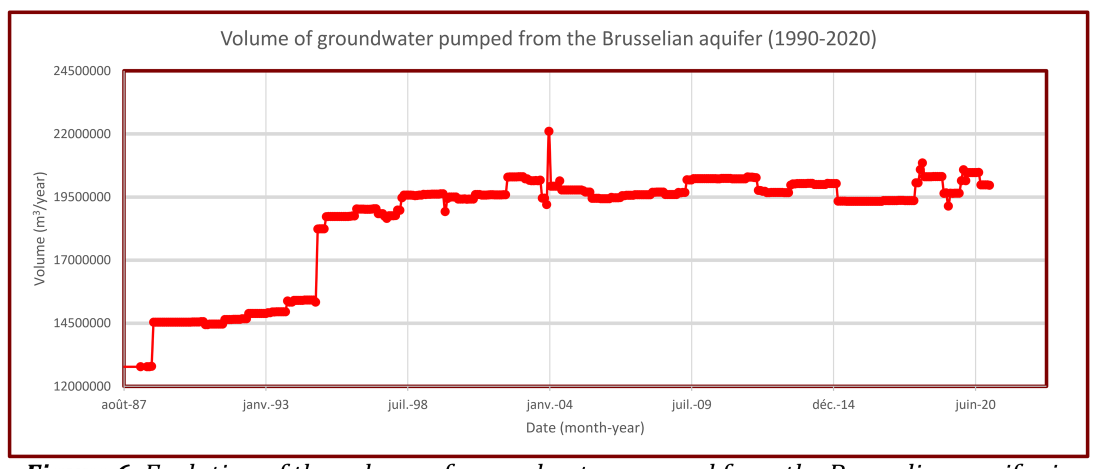


Figure 6. Evolution of the volume of groundwater pumped from the Brusselian aquifer in the delimited study area around Leuven, Belgium.

A 3D groundwater flow model integrating the different geological formations, the hydrogeological parameters, the stress factors (see Figure 6) and historical data for the area of Leuven has been developed. The model has been calibrated in steady state (Figure 7). The model will be now calibrated in transient conditions and then be coupled with a geomechanical model for consolidation and rebound calculation.

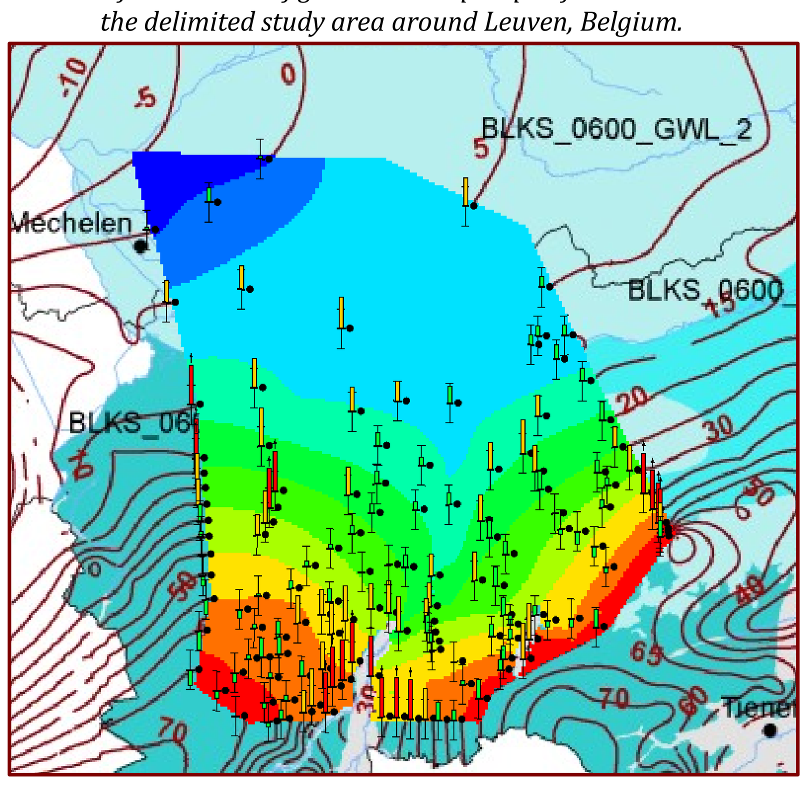
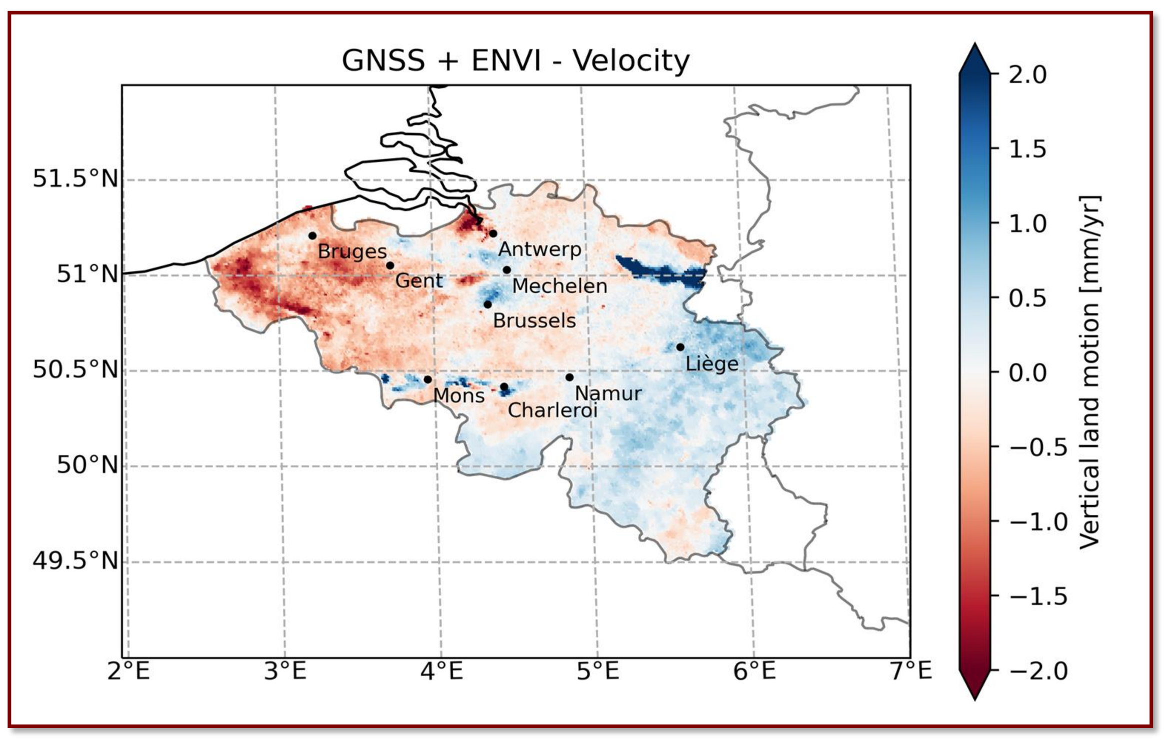


Figure 7. Computed piezometric map in the Brusselian aquifer. In background, observed piezometric map (VMM, 2016). Control points with a 5 meter error gauge related to the calculated piezometric head compared to the piezometric map.

Large-Scale Map of Subsidence over Belgium using PS-InSAR and Robust Network Imaging



Combining both GNSS and PS-InSAR data to reconstruct vertical land motions over Belgium

- GNSS observations allow computing geocentric velocities of a network of GNSS stations separated by a few tens of kilometers.
- PS-InSAR data allows deriving the deformation field with a much higher resolution, but relative to an arbitrary local reference.

Figure 8. Vertical land motions in Belgium resulting from the combination of PS-InSAR and GNSS data. GNSS position time series from Nevada Geodetic Laboratory. SAR data : ENVISAT date

Using the Robust Network Imaging technique proposed by Kreemer et al., (2020), we imaged the VLM resulting from GNSS and PS-InSAR on a 0.01° x 0.01° grid. Because PS-InSAR can present large-scale artifacts, we filtered out the short-wavelength deformation from PS-InSAR using a median filter with a 25 km radius and combined it with large wavelength deformation retrieved by GNSS (Figure 8). This allows quantifying both the large-scale pattern (i.e., Eifel uplift and coastal subsidence) along with the local deformation.

Toward Next Steps

The following steps will be accomplished through future steps:

1. Using high resolution TerraSAR-X radar dataset to have more accurate mapping of ground displacement.
2. A 3D groundwater multi-layer model simulating water level under transient state along with a 1D geomechanical model simulating subsidence in those layers will be developed for each target area.
3. Combining all measurements observed by the Global Navigation Satellite System (GNSS) statistic network over Belgium belonging to Nevada Geodetic Laboratory (NGL) with repeated absolute gravity measurements and PS-InSAR measurements to either validate PS-InSAR data or retrieve displacement measurements in those areas where no PS points are observed by the radar sensor.
4. Comparison of results from different techniques to better interpret the causes and effects of ground deformations.
5. Future measurements of land surface displacements will be achieved by installing different sets of devices called corner reflectors equipped with professional GNSS stations. Corner reflectors will be illuminated by radar satellite as PS's and their displacements values will be verified by the GNSS observations attached to them.

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