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Remote sensing activities to support the Sustainable Development Goals

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Abstract

The Sustainable Development Goals are 17 goals set up by the world leaders to be achieved by 2030 that respond to the world's main development challenges. Such Goals are complemented by many targets and are to be measured by a large set of indicators. Remote sensing, with its capability to monitor systematically several parameters at global scale, can surely provide a valuable support the Sustainable Development Goals. In this paper we describe the remote sensing experience of the authors, which can be relevant to different Sustainable Development Goals. Such an experience is mainly based on active radar remote sensing using Synthetic Aperture Radar and the interferometric technique. However, this paper also describes studies that are based on other remote sensing techniques. The paper discusses six types of remote sensing applications: urban deformation monitoring; landslide and subsidence monitoring; deformation monitoring related to mining activity and mining security; glacier velocity monitoring; environmental monitoring; and coastal monitoring.

1. Introduction

The Sustainable Development Goals (SDGs), adopted by all United Nations Member States in 2015, provide a policy-making baseline for countries to overcome shortcomings and barriers for people and the planet Earth by 2030. Remote sensing can play a role in supporting the SDGs, allowing us to carry out an evidence-based policy making, thus contributing to the realization of the SDGs by monitoring the indicators.

This paper summarizes the experience of the authors in this field. This is mainly based on active radar remote sensing using SAR (Synthetic Aperture Radar) and the interferometric (InSAR) technique, complemented by other remote sensing techniques. We describe in the following:

- Urban deformation monitoring by InSAR. This activity is mainly related to SDG11, “Sustainable cities and communities”.
- Landslide and subsidence monitoring by InSAR. This can contribute to SDG13, “Climate Action”, and SDG11, “Sustainable cities and communities”.
- Deformation monitoring related to mining activity and mining security by InSAR. This is related to SDG7, “Energy Access and Sustainability”, SDG9, “Infrastructure, Innovation and Industrialization”, and SDG15, “Life on Land”.
- Glacier velocity monitoring by InSAR and Pixel Tracking. This can contribute to SDG13, “Climate Action”.
- Environmental monitoring using SAR, optical and multi-spectral remote sensing. This is related to SDG13, “Climate Action”.
- Coastal monitoring using InSAR and optical remote sensing. This contributes to SDG11, “Sustainable cities and communities”, SDG13, “Climate Action”, and SDG15, “Life on Land”.

The above applications are based on the experience of the authors. The relevance of some of such applications, especially those based on InSAR, is now amplified by the availability of the European Ground Motion Service (EGMS), an InSAR-based deformation service of Copernicus, the Earth Observation Programme of the European Union, that covers all Europe (see https://egms.land.copernicus.eu/). Thanks to EGMS, the applications that, in the last two decades, were typically carried out locally can now be performed at national level or even at continental European level, increasing their relevance to SDGs.

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2. Examples of remote sensing applications

2.1 Urban deformation monitoring by InSAR

InSAR is a powerful remote sensing technique to monitor land deformation. The technique works particularly well over urban areas and infrastructures. This is because man-made objects (buildings, structures and infrastructures) are optimal targets for InSAR (Crosetto et al., 2016).

The InSAR technique for deformation measurement was introduced for the first time by Gabriel et al. (1989). Since then, and especially with the advent of the ERS-1 SAR imagery, InSAR-based urban deformation monitoring has become widely used. At the beginning of 2000, an advanced version of InSAR was introduced (Ferretti et al., 2000; 2001), which was called Persistent Scatterer Interferometry (PSI). This further fostered the use of InSAR (e.g., see Hanssen, 2001).

Figure 1 shows an example of InSAR-derived deformation velocity map. In this map, the velocity values are colour-coded (between blue, corresponding to -7.5 mm/y and red, corresponding to +7.5 mm/yr) and superposed to a SAR amplitude map. One may notice that the colour points do not cover all the area. This is because the technique works well mainly over man-made objects, and not over vegetated and forested areas.

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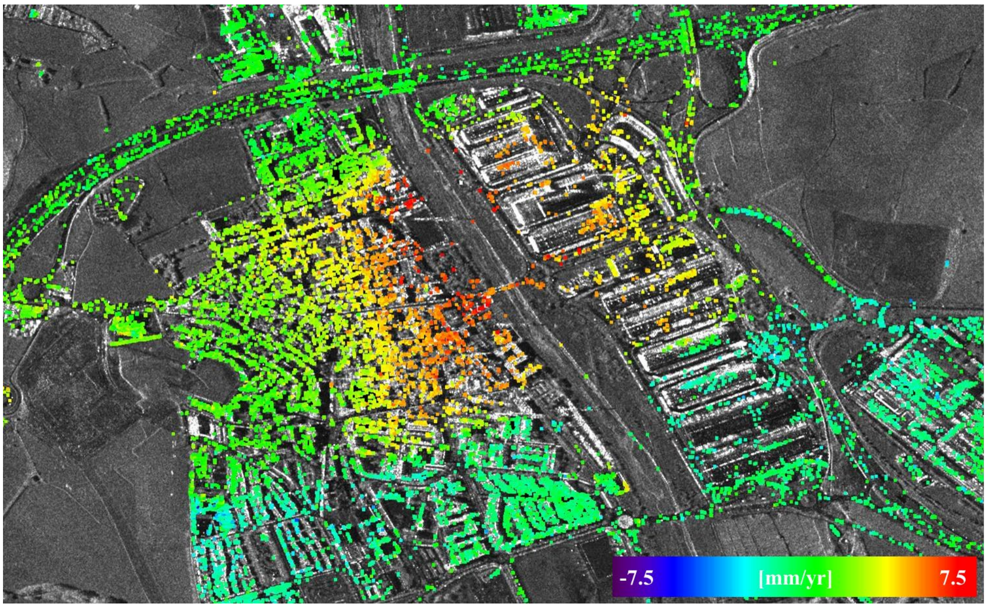

Figure 1: example of deformation velocity map over a small town located in Catalonia (Spain).

By InSAR is it possible to monitor the stability of buildings, structures and infrastructures. A typical application is the monitoring of subsidence phenomena. Another important application is the monitoring of the deformations associated to construction works, especially those that involve changes in the water table. The urban deformation monitoring by InSAR can contribute to SDG11, "Sustainable cities and communities".

2.2 Landslide and subsidence monitoring by InSAR

InSAR is widely used to monitor landslides and subsidence areas. In the last years, InSAR and PSI have improved their performance, particularly in terms of capability to cover wide areas. We intend by wide areas, the monitoring of entire regions or even nations. This is possible due to the availability of systematic SAR acquisitions over large areas; the readiness of mature InSAR processing tools; and the access to powerful computational resources. The most important example of wide-area InSAR is the European Ground Motion Service (EGMS), part of European Copernicus Programme (Crosetto et al. 2020; Crosetto and Solari, 2023). This service operates at European continental scale, with the potential to expand globally in the future.

As said, InSAR and PSI offer a solution for tracking and analysing landslide activity. Just considering the work related to EGMS, several studies have demonstrated their effectiveness. For instance, research focusing on single landslides is described in Yishu (2022), Godone et al. (2023), and Dabiri and Nilfouroushan (2024). Broader studies focused on landslide inventories are described in Necula and Niculiță (2023), Guinau et al. (2024), and Medici et al. (2024). An example of InSAR-based landslide monitoring is shown in Figure 2.

There are several examples of InSAR-based subsidence monitoring. Some of them are related to monitoring aquifer dynamics, e.g. see Béjar-Pizarro et al. (2017), and Li et al. (2024). Figure 1 is an example of subsidence monitoring. Landslide and subsidence monitoring by InSAR can contribute to SDG13, "Climate Action", and SDG11, "Sustainable cities and communities".

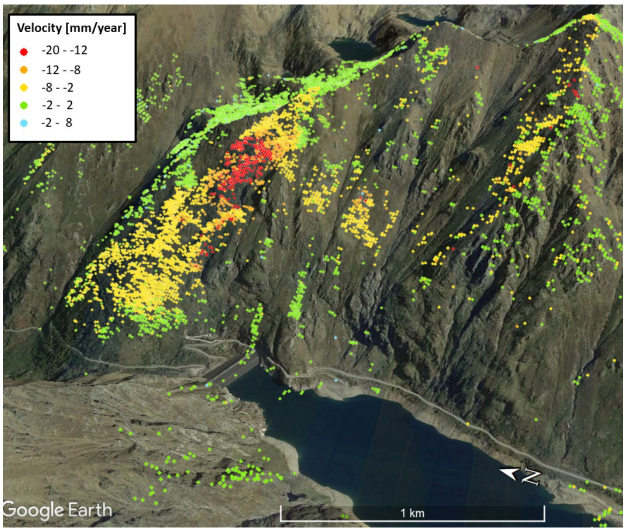

Figure 2: example of InSAR-based landslide monitoring. Deformation velocity values superposed to Google Earth.

2.3 Deformation monitoring related to mining activity and mining security by InSAR

A sector where InSAR products are used at operational level is mining. Several companies worldwide provide InSAR deformation monitoring to mining companies. The monitoring can regard underground mining (looking at the impact on the surface), open pit mines (monitoring the stability of the open pit slopes and the surrounding areas), mine installations, and abandoned mines, e.g. see Pawłuszek-Filipiak et al. (2023), Motagh et al. (2024), and Tzampoglou and Loupasakis (2023).

Figure 3 show an example from the SMILE project. In this case InSAR was used to derive both the deformations that affect the open pit mine and the so-called residual topographic error, which describes the difference between the actual topography (the open pit) and the topography prior to the pit excavation.

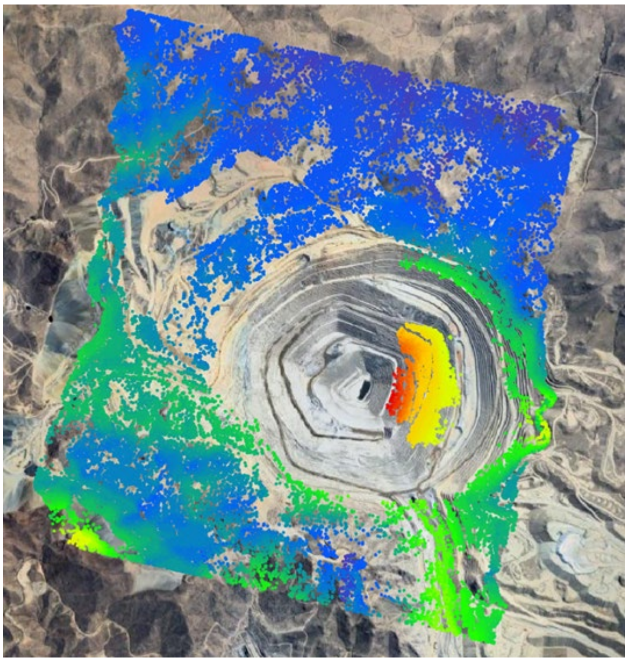

Figure 3: InSAR-based monitoring based on the joint exploitation of TerraSAR-X and Sentinel-1 SAR imagery. The figure shows the map of the residual topographic error (from about -800 m, in red, to approximately 0 m in blue). This map was generated at CTTC in the frame of the SMILE project.

2.4 Glacier velocity monitoring by InSAR and Pixel Tracking

Glaciers play a critical role in climate monitoring. Observing their dynamics is key for studying their response to a changing climate and predicting their evolution. An important glacier monitoring product is glacier velocity. In fact, climate change is not only driving glacier retreat, but also, in some areas, driving large-scale changes in glacier ice-flow dynamics and velocity. Measuring glacier velocity is therefore essential for understanding the impact of climate change on ice dynamics.

InSAR can monitor glacier dynamics, particularly when using single pairs of SAR images (Strozzi et al., 2002). However, this only provides Line-Of-Sight (LOS) measurements and is affected by errors due to phase unwrapping. In general, PSI is not suitable for monitoring glacier motion due to the temporal decorrelation commonly associated with moving ice.

By contrast, an effective technique is given by the Pixel Offset Tracking (POT) technique and SAR imagery. By correlating amplitude images, POT has the advantage to estimate displacements in both the range and azimuth directions, thereby capturing the direction and magnitude of glacier flow (Michel and Rignot, 1999; Joughin, 2002). POT does not require phase unwrapping, making it more robust in rapidly deforming areas. An example of POT measurement is shown in Figure 4.

Glacier velocity monitoring by InSAR and Pixel Tracking can contribute to SDG13, “Climate Action”.

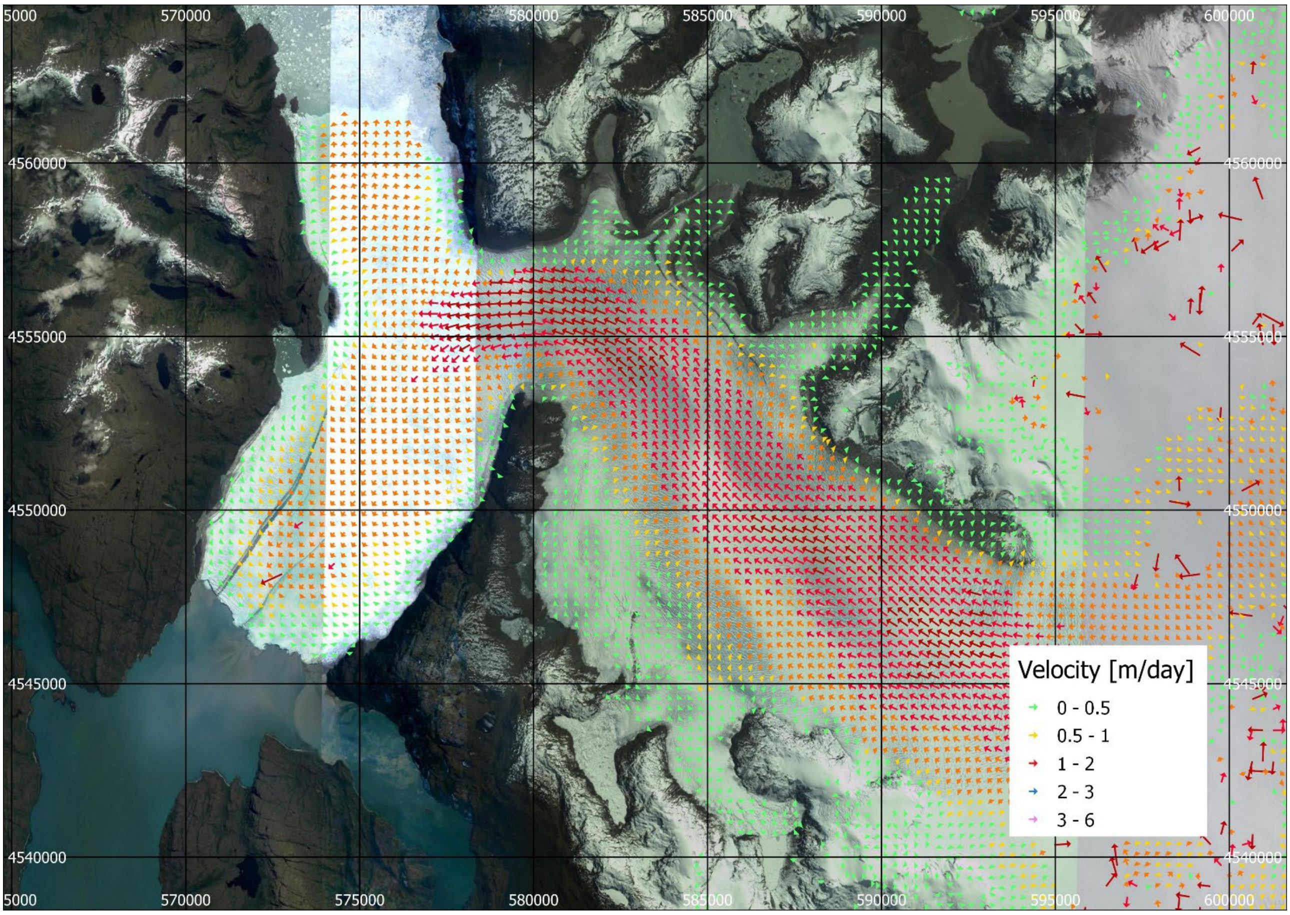

Figure 4: glacier velocity estimated using Pixel Offset Tracking. Example over Campos de Hielo Sud (Chile).

2.5 Environmental monitoring using SAR, optical and multi-spectral remote sensing

Environmental monitoring can largely benefit from the continuous observation capabilities of current remote sensing satellites. There are uncountable applications of this type of monitoring, which can offer medium to high spatial resolution, relatively high temporal resolution, wide-area coverage at relatively low cost (Li et al., 2020).

The most important source for environmental monitoring is optical remote sensing, which exploits multi-spectral bands in the visible range of the electromagnetic spectrum and bands close to visible. In several applications, additional useful information can be derived by fusing multi-spectral and SAR data. The latter data can include the SAR amplitude imagery and other interferometric products, like the coherence images. Environmental monitoring based on SAR, optical and multi-spectral remote sensing can provide a fundamental contribution to SDG13, “Climate Action”.

In the following we describe an example of vegetation monitoring in an arid ecosystem. This type of application is crucial for achieving the SDG15, “Life on Land”. Monitoring plant health helps mitigate climate change, because vegetation acts as a carbon sink. Monitoring vegetation is also essential for conserving biodiversity and the ecosystem services that sustain local life. This is especially true in extremely fragile ecosystems, e.g. saline ecosystems, where species are highly adapted to salinity conditions. An example of monitoring such ecosystems is shown in Figure 5. These results are part of the SMILE project mentioned earlier in the introduction of this paper.

Figure 5A shows the Lagoon of Tebenquinche (Chile), which is located in the northern sector of the Salar de Atacama. This is an example of high Andean wetland, which plays a significant role in the ecological dynamics of the Salar de Atacama. Figure 5A was derived by averaging 195 Sentinel-2 images that cover the period from July 2022 to July 2025.

Figure 5B shows the estimated spatial distribution of surface vegetation near the Lagoon of Tebenquinche. In this context "frequency" means the number of times that the value of the vegetation index is above a given threshold over the considered period (0.3).

Figure 5C shows the temporal distribution of surface vegetation. An expansion of the vegetation surface can be observed during the southern hemisphere's spring. By contrast, it decreases during the fall and during the winter, the surface area is almost zero. Considering the precipitation, which is shown in Figure 5C, the dynamics of the vegetation do not appear to be related to it. Due to the location of the lagoon in the desert, one could infer that underground water is the main source to feed the vegetation.

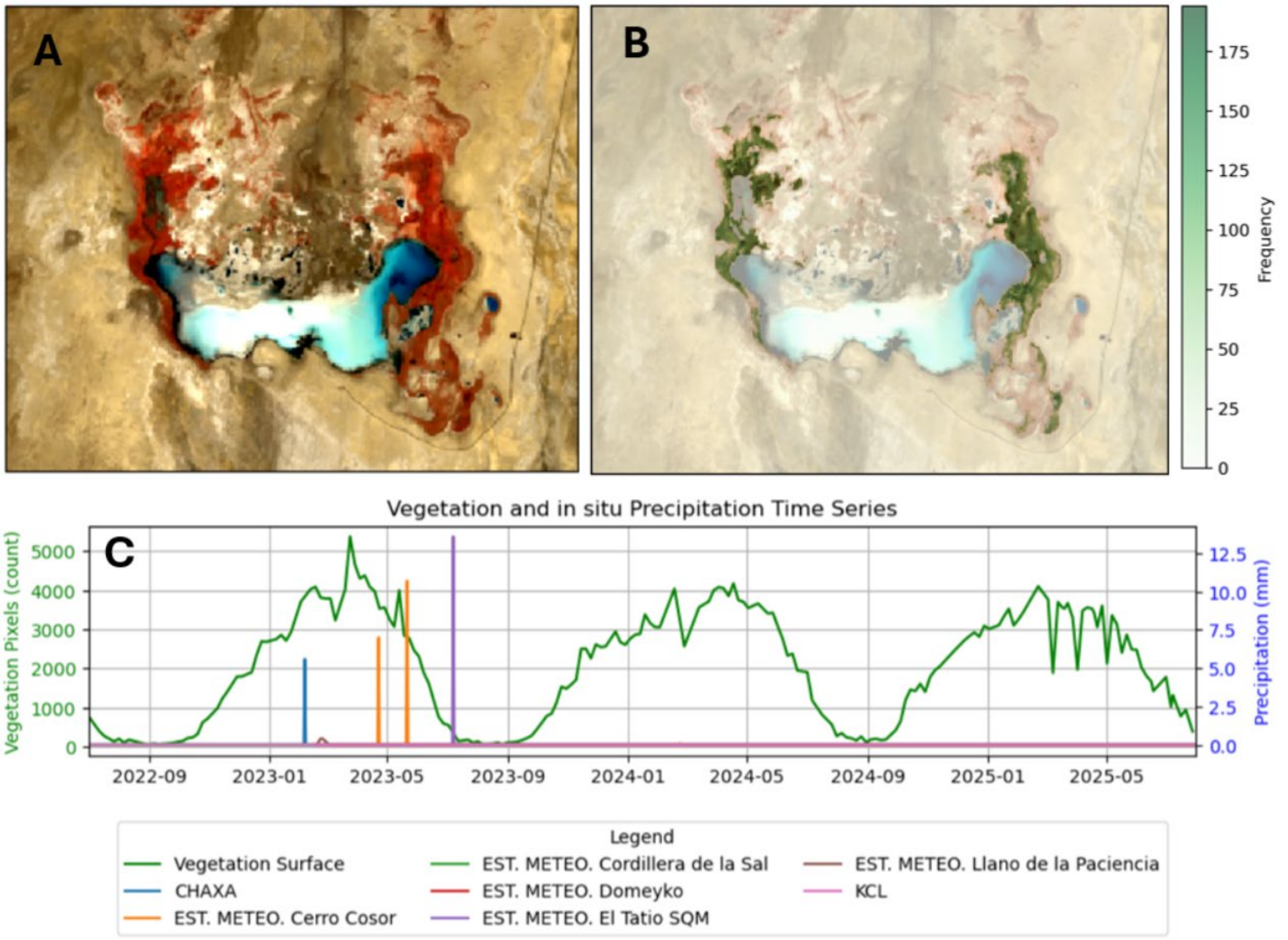

Figure 5: Laguna Tebenquinche. Sentinel-2 average image over the period July 2022 to July 2025 (A). Spatial distribution of surface vegetation near Laguna Tebenquinche (B). Vegetation and in situ precipitation time series (C).

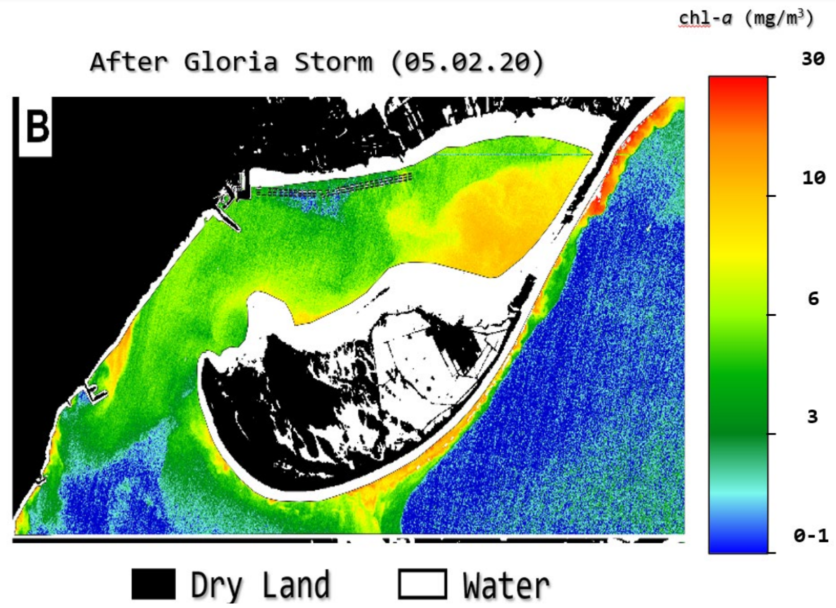

Figure 6: map of chlorophyll-a concentration and changes detected after the Gloria storm in the Ebro Delta (Spain).

2.6 Coastal monitoring using InSAR and optical remote sensing

Another important remote sensing application is coastal monitoring. Like in the environmental monitoring, coastal monitoring can be based on optical, multi-spectral and radar data (Klemas, 2011).

In Figure 6 we show an example of coastal monitoring in southtern Catalonia (Spain). The objective was quantify the effects of storm Gloria, a major storm that affected eastern Spain and southernmost France with high winds and heavy rainfall. The focus here was on water quality, assessing chl-a, a specific form of chlorophyll that is used in oxygenic photosynthesis, and on changes in the geomorphology of this coastal area.

The input image used in this study was Sentinel-2 (L1C), after applying an atmospheric correction. The chl-a map shown in Figure 6 was generated with a semi-empirical model that combines different spectral bands and that was calibrated with field data from a period of 2 years.

For the coastal geomorphology part, the changes were detected by generating a land-water mask from an unsupervised classification algorithm, and observing the discontinuities between the land and water. One may observe that within the bay there is a high chl-a gradient, certainly due to the presence of a lot of suspended matter due to the storm, while from a geomorphological point of view, the loss of a very significant part of the beach (Barra del Trabucador) due to the storm is clearly observed (instead of a continuous black strip there is a white strip).

The result from Figure 6 is just an example of the uncountable applications related to coastal monitoring. The use of remote sensing can help in managing coastal territory, which often consist of extensively modified natural spaces, under strong urban development pressure, where terrestrial and marine processes interact, and that are often vulnerable to the effects of climate change. The continuous monitoring based on remote sensing data and analysis tools can substantially contribute to SDG11, “Sustainable cities and communities”, SDG13, “Climate Action”, and SDG15, “Life on Land”.

3. Conclusions

In this paper the remote sensing experience of the authors, which can be relevant to the SDGs, has been described. Such an experience is mainly based on active radar remote sensing using Synthetic Aperture Radar and the interferometric technique (InSAR). However, study based on other remote sensing techniques have been described.

Six main fields of application have been addressed, which include: (i) Urban deformation monitoring by InSAR; (ii) Landslide and subsidence monitoring by InSAR; (iii) Deformation monitoring related to mining activity and mining security by InSAR; (iv) Glacier velocity monitoring by InSAR and Pixel Tracking; (v) Environmental monitoring using SAR, optical and multi-spectral remote sensing; and (vi) Coastal monitoring using InSAR and optical remote sensing.

The SDGs provide a policy-making baseline for countries to overcome shortcomings and barriers for people and the planet Earth. Remote sensing data and methods can surely support the SDGs, allowing us to carry out an evidence-based policy making, thus contributing to the realization of the SDGs.

In order to provide a solid support to SDGs, the following aspects are key:

- Ensure high-quality of the primary data acquired by satellite sensors.
- Warrant an appropriate temporal (related to satellite revisiting time) and spatial (related to sensor resolution) sampling of the entire globe.
- Guarantee high standards in the tools to perform satellite data processing and analysis.
- Perform continuous data validation.
- Ensure dissemination levels adequate to the different uses of the results derived by remote sensing.

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