remote sensing

Editorial

Editorial for the Special Issue: "Ground Deformation Patterns Detection by InSAR and GNSS Techniques"

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In the last two decades, the rapid growth in continuous Global Navigation Satellite Systems (GNSS) networks and improvements in Interferometric Synthetic Aperture Radar (InSAR) imaging allowed the acquisition of continuous and spatially extensive datasets over large regions of Earth, significantly increasing the range of geoscience applications. In addition, the promising results obtained by the scientific community and the free availability of data, which permitted drastic cost reductions, have drawn increasing interest from the administrative managing office for the mapping and monitoring of ground deformation issues.

This Special Issue aims to provide a general overview of some geoscience applications of GNSS and InSAR techniques which are commonly used to study the surface deformation related to co- and post-seismic deformation, subsurface movements of magma beneath active volcanoes, soil deformation (e.g., natural/anthropic uplift or subsidence), monitoring of landslide, monitoring of industrial settlements, the motion of ice sheets, etc. The GNSS technique provides a set of 3D geodetic observations at a limited number of points on the ground surface. The continuous technological development in GNSS equipment currently allows collecting measurements at higher rates (up to 100 Hz), offering a wide range of new applications for solid and fluid Earth investigations. The InSAR technique provides a spatially dense set of geodetic observations of ground deformation in the viewing geometry of the satellite sensor, and with a temporal sampling limited to the satellite orbital revisit (up to 6 days with the Sentinel constellations). Any deformation of the ground surface can be measured by comparing two radar images of the same area, collected at different times from approximately the same position in space. InSAR processing advancements also allowed multi-temporal analyses, which sensibly improved the investigation of long-term deformation events.

GNSS and InSAR measurements can complement each other and are generally combined to infer the 3D surface deformation over a target region. A review of more than 190 studies dealing with InSAR and GNSS combined measurements has been proposed in Del Soldato et al. [1]. The ground deformation measurements coming from both techniques have been combined for different purposes [1], evidencing how their joint use has been readily employed by the scientific community as well as by stakeholders and environmental managers. In turn, the increasing range of applications started to push the development of new approaches aimed at fast and robust combinations of GNSS and InSAR measurements. In such a frame, Xiong et al. [2] proposed an iterative least squares approach for virtual observation (VOILS) based on the maximum a posteriori estimation criterion of Bayesian theorem while Parizzi et al. [3] developed an approach accounting for the spectral properties of the errors of InSAR and GNSS measurements, hence preserving all spatial frequencies of the deformation detected by the two techniques. Both methods have been tested and validated with both synthetic and real data. Achieved results highlighted that both methods led to significant improvement of the spatial accuracy of the combined deformation field, therefore allowing accurate detection of the ongoing deformations.

Several studies included in this Special Issue focused on the co-seismic deformation related to moderate to large earthquakes. De Novellis et al. [4] focused on the March 2021 Thessaly seismic sequence (Central Greece) highlighting the activation of unknown distinct blind fault segments in a sort of domino effect within the seismogenic crustal volume. Caporali et al. [5] analyzed the seismic sequence of November 2019 in Albania and inferred a NE-dipping reverse seismogenic fault located at a depth of 8 $\pm$ 2 km. Sakkas [6] focused on the 30 October 2020 M_w6.9 Samos Island (Aegean Sea) earthquake and suggested that the earthquake nucleated on a two-segments north-dipping listric fault characterized by a predominant dip-slip component and a minor lateral one. The complex deformation field associated with the April 2016 Kumamoto (Japan) seismic sequence was analyzed by He et al. [7] which modelled a four-segment fault geometry with right-lateral strike-slip kinematics coupled with a minor normal slip component. Valerio et al. [8] focused on the 7 November 2019 M_w5.9 earthquake hitting the East-Azerbaijan region and proposed a shallow NE-SW striking and SE-dipping fault as the seismogenic source. All these studies clearly proved that GNSS and InSAR data analysis and modelling are extremely useful tools in helping to constrain the causative fault of moderate to large earthquakes, especially in the case of blind and unknown faults, therefore providing useful information on the seismic hazard estimation of the investigated areas.

Active faults can be also affected by long-term creeping during the interseismic period. Geodetic observations are used to investigate co- and post-seismic deformations as well as transient deformations at least when these phenomena yield deformations high enough to be discriminated from long-term trends. However, there could be the possibility that the whole amount of observed long-term deformation could be partially or totally caused by inelastic processes instead of related to the building of elastic stress preparing the next earthquakes. Cambiotti et al. [9] focused on this topic by proposing a novel inverse method aimed at the discrimination of regional deformation and of long-term fault creep by inverting available GNSS measurements. Sparacino et al. [10] performed a seismic and geodetic moment-rates comparison for the western Mediterranean to identify that regions where the total deformation-rate budget is entirely released by crustal seismicity, and the ones where the excess deformation-rate can be released either in aseismic slip across active faults or through large future earthquakes. Achieved results by both studies proven that the geodetic measurements represent an essential part of the seismic-hazard analysis on highly deforming regions.

Other studies included in this Special Issue focused on the surface deformation related to the migration of fluids along the magmatic system of active volcanoes. Galvani et al. [11] analyzed twenty years of GNSS and levelling measurements collected on Ischia Island (Italy) and found a deflating source located at a depth of 4 km below the southern flank of Mt. Epomeo. Battaglia et al. [12] studied the subsidence of Dallol volcano (Erta Ale ridge of Afar, Ethiopia) and inferred a deflating source located beneath the volcano edifice at a depth ranging in the 0.5–1.5 km interval and characterized by a volume decrease between -0.63 and -0.26×10^6 km^3/year. Boixart et al. [13] focused on the Sabancaya volcano (southern Perú), detecting an active deep source of deformation located between the Sabancaya and Hualca volcanoes with a volume change rate of 26×10^6–46×10^6 m^3/yr. These studies evidenced that GNSS and InSAR techniques can detect and track with high detail the spatial and temporal evolution of the magmatic system during a volcanic crisis. Both techniques are essential tools for the continuous monitoring of active volcanoes as well as to understand magmatism, refine volcano models, and mitigate volcanic hazards.

Another topic addressed in this Special Issue is that of land subsidence which can occur for both natural and anthropic causes. Land subsidence represents a relevant issue that might affect highly developed urban and industrialized areas. Cando Jácome et al. [14] focused on the land subsidence due to the underground mining which is causing the collapse of many buildings in the urban area of Zaruma in Ecuador. The authors proposed a forecasting methodology for the continuous monitoring of the long-term soil subsidence in target areas, largely improving the traditional detection performed with total stations and geodetic marks. Mohamadi et al. [15] designed a PS-InSAR-based workflow on the detection of unusual vertical surface motions in urban areas in order to create temporal vulnerability maps for building collapse monitoring. Both studies highlight that the development of methodologies for the continuous monitoring of the land subsidence is strictly required to improve security standards aimed at the building collapse risk reduction in densely urbanized areas.

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