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Introduction to the Special Issue Geoscience in Active Areas

U. Riccardi,[1,7] J. Arnoso,[2,7] D. Gómez-Ortiz,[3,4] C. Del Negro,[5] and F. Sigmundsson[6]

The Special Issue (SI) of Pure and Applied Geophysics titled "Geoscience in Active Areas" has gathered 21 contributions from a wide range of geoscience disciplines, including geophysics, geodesy, geology, seismology, volcanology, oceanography and tectonics giving the opportunity to exchange leading edge ideas on a broad range of topics focused on volcanic and seismically active areas of the Earth. A key achievement of this volume is to communicate that the multidisciplinary approach is the way forward for a holistic understanding of volcanic and seismic phenomena and their tectonic origins. It wants to report on the state of art efforts of geoscience community to mitigate the geohazards in some of the most dangerous territories of the world, where inhabitants and infrastructure are exposed to extreme natural hazards associated with peculiar tectonics and geodynamics of the regions. Most of these hazards relate to continent–continent collisions between Indian and Eurasian Plates, as it is in the Himalaya region or the interaction between Eurasian and Nubia Plates, as for active volcanic areas of Southern Italy, Azores and Canary archipelagos or rapid plate convergence of the Pacific plate, as in the case of Taiwan. This tectonic interplaying has caused significant earthquakes and one of the largest, if not the largest explosive volcanic event in Europe in the past 200,000 years (the Campanian Ignimbrite eruption at Campi Flegrei).

This SI has even collected a selection among the most significant investigations presented at the International Workshop on "Geosciences in Active Areas", organized by the Institute of Geosciences, IGEO (CSIC-UCM) and the House of Volcanoes (Cabildo de Lanzarote) held in Lanzarote in October 2023. The IGEO leads the geosciences laboratory of Lanzarote, which focuses on investigating geodynamic activity in this volcanic area. Following years of rigorous experimentation in this laboratory, Benavent et al. (2024) analysed tide gauge data from 2005 to 2023 to study short- and long-term sea level changes. As described by the authors, sea level trends are influenced by climate variability, complicating their interpretation even with long datasets. Using multi-year (3–10 years) and decadal time scales, the authors investigate sea level connections with climate indices such as sea surface temperature, sunspots, and the North Atlantic Oscillation (NAO). Wavelet analysis and cross-wavelet coherence are the methods used to examine correlations between sea level and climate indices. In addition, linear regression models, incorporating periodic components, are employed to quantify sea level changes. Additionally, the analysis of GNSS data co-located with the tide gauge revealed a sea level rise of 0.33 ± 0.06 cm/year and vertical ground displacement of 0.016 ± 0.003 cm/year over the studied period.

In Duan et al. (2024) an innovative method to determine precisely normal height differences is presented. The method called "GNSS Gravity

[1] Dipartimento di Scienze della Terra, Dell'Ambiente e delle Risorse (DiSTAR), Università "Federico II" di Napoli, Naples, Italy. E-mail: umbricca@unina.it
[2] Instituto de Geociencias (IGEO, CSIC-UCM), Madrid, Spain.
[3] Departamento de Biología y Geología, Física y Química Inorgánica, Escuela Superior de Ciencias Experimentales y Tecnología, Universidad Rey Juan Carlos, C/Tulipán s/n, 28933 Móstoles, Madrid, Spain.
[4] Research Group "Geofísica y Geoquímica Ambiental", Universidad Rey Juan Carlos, 28933 Móstoles, Madrid, Spain.
[5] Istituto Nazionale di Geofisica e Vulcanologia, Catania, Italy.
[6] Nordic Volcanological Center, Institute and Faculty of Earth Sciences, University of Iceland, 102 Reykjavik, Iceland.
[7] Research Group "Geodesia" (GRG-UCM), Universidad Complutense de Madrid, 28040 Madrid, Spain.

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Levelling" consists in an integration of GNSS observations, gravity field models, and actual gravity measurements. The problem of the normal height difference is well solved and the accuracy of the method is validated in a test region, characterized by harsh topography (including slopes, valleys and mountain ridges). This method could constitute a modern solution for height measurement which can replace the time-consuming high-precision leveling surveying. It could have promising applications in geodesy and monitoring of seismic and volcanic active areas. The measurement of strain change in the Earth's crust is fundamental to improve our understanding of long-term tectonic deformation. Mandler et al. (2024) propose a new methodology to accurately calibrate borehole strainmeters of type Gladwin Tensor Strain Monitor (GTSM). GTSM sensors are designed to measure relative strain variations with a resolution greater than strain at periods of minutes to months. The authors report on their experience with 4 arrays of GTSMs that were installed in Taiwan, to intensify the earthquake monitoring system in one of the most active areas on the Earth. The suggested calibration method is based on waveform modelling of Earth and ocean tidal strain-related deformations. They demonstrate that a simple quasi-isotropic approach based on tidal waveform modelling is suitable to resolve the orientation and the calibration of the tensor signals, even in very noisy conditions.

The joint analysis of seismicity and ground deformation in active volcanic areas, can reveal some aspects of the volcano dynamics related to fracture processes or unveil the coupling between fluid flow and vibrating solid structure. Falanga et al. (2024) offer an interesting review of the most relevant results obtained in recent works on the Neapolitan Volcanoes: Campi Flegrei, Ischia, and Vesuvius (Southern Italy) regarding the coupling between ground deformation detected by tiltmeters and volcano-tectonic seismicity. The Neapolitan volcanoes are among the highest-risk volcanic areas in the world because of the high-density population. Thus, Riccardi et al. (2024) perform a very valuable study on the residual gravity signal to be interpreted in terms of the present-day dynamics of the Campi Flegrei active volcanic caldera. The authors carry on a comprehensive analysis to identify unusual trends in coincidence of the most energetic volcano-tectonic events and seismic swarms recorded during January 2023 to February 2024. The main finding of this research suggests that the gravity variations analysed are primarily driven by non-linear drift components that have not been perfectly modelled by the current approach, although without ruling out the possibility that some of the analysed signals may be produced by subsurface mass redistribution. The authors also conclude that for volcano surveillance it is critical to retrieve gravity residuals free of instrumental effects when using systems relying on spring-based gravimeters. Focussing now on the small volcanic islands of Lipari, Salina, and Vulcano in the Aeolian archipelago, Polcari et al. (2024) evaluate the performance of Multi-Temporal InSAR (MT-InSAR) techniques—PS, SBAS, and IPTA—in monitoring ground deformation. The techniques are assessed for their spatial coverage, coherence, and ability to detect linear deformation trends, with results compared against GNSS data using various metrics. SBAS offers better spatial coverage and more measurement points but may yield unreliable results in low-coherence areas, as seen for Salina Island. PS excels in detecting localized deformation with high accuracy but suffers from limited point targets in non-urban areas, complicating analyses like the 2021 Vulcano crisis. IPTA integrates strengths of both methods, balancing spatial coverage and accuracy, but results can vary due to less rigorous point target selection. Regarding the processing times and storage requirements, the authors conclude that SBAS is computationally intensive, while IPTA and PS techniques are faster but demand high-resolution data. Consequently, no single technique is universally optimal; customization by expert users is necessary to refine parameters for specific scenarios. In another different volcanic active area of the planet, Suarez et al. (2024) provide a joint interpretation of seismic analysis based on an automated deep learning approach and PPP processing of GNSS data, offering new insights into the magmatic intrusion that occurred at São Jorge Island (Azores archipelago) in 2022. The authors identify a four-stage process that explains the ascent of magma and the emplacement of a dike that stagnated before reaching the surface, an overpressure due to the lateral expansion of the magma body in a sill-like distribution and, finally, a decline in magma accumulation that prevented the expansion of the sill. This study highlights the value of these processing analyses and methods as a tool for interpreting volcanic unrests, which is an essential resource for authorities and civil protection teams, enabling a rapid response.

The question of how earthquakes can influence the ionosphere has long been debated by many authors in search of precursors for earthquake prediction. Although some theories have been proposed, the precise mechanism linking ground-level electromagnetic signals to ionospheric anomalies remains elusive. Eshkuvatov et al. (2024) investigate the potential of ionosphere anomaly for earthquake prediction and identified several effects that could serve as earthquake precursors. From the analysis of GPS data ionospheric precursors were identified 4 days before the Afghanistan $M = 6.0$ EQ of June 21, 2022. Correlations were found between electron density measurements obtained by satellites moving in the upper ionosphere and variations observed in GPS observations before the earthquakes. The theoretical analysis provided measurable values for the group delay variation of GPS signals propagating through the upper ionosphere during earthquakes. Their main findings suggest that the correction to the group delay of the wave holds significant promise for practical application in earthquake prediction, particularly through GPS monitoring of the ionosphere.

The Himalaya is one of the Earth's most seismically active continent–continent collisions created when the Indian Plate collided with the Eurasian Plate. The region is renowned by its complexity, as a consequence of the interaction between the strain field and mechanical properties of the lithologies involved in the collisions. Numerous tectonic models have been proposed to explain the complex evolution of the Himalayan Mountain range. In this topical issue two contributions are devoted to the Himalaya area. Rai et al. (2024) estimated earthquake source parameters and spectral decay characteristics of 80 small earthquakes occurred in Siang Region of Arunachal Himalaya. Although it exhibits an interesting and complex range of tectonic characteristics, this is a relatively unexplored and understudied natural area, particularly in the realm of seismological investigations. The results are exhaustively discussed in terms of their implications to structural heterogeneities and complex seismotectonic processes underlying the Arunachal Himalaya region. Vashisth et al. (2024) investigated the source characteristics of earthquakes and their scaling relationships in the Uttarakhand and Himachal Pradesh area of Himalaya, a region that has been struck by four destructive earthquakes since the turn of the century. Earthquake source parameters and high-frequency spectrum decay of 247 earthquake events with magnitudes ranging from 3.0 to 5.5 are assessed and discussed in relation with the complex geological structures and the intricate earthquake processes in these regions.

Yu et al. (2024) used Sentinel-1A InSAR observations to obtain the co-seismic deformation field, the source parameters and seismogenic fault model of the 2024 Mw 7.0 Wushi (Xinjiang, China) earthquake. The geometric parameters of the seismogenic faults jointly with the distribution of the co-seismic slipping are inverted, assuming the Okada elastic half-space dislocation model (Okada, 1985). The authors discuss the main characteristics of the deformation field, nature of the fault motion as well as the seismogenic structure. From the seismic activity in the earthquake sequence, they retrieve evidences of crustal shortening in the southern Tianshan region. This could have been facilitated by the absorption of compression from the frontal compressional thrust belt and high-angle reverse faults in the orogenic belt.

It is largely accepted that independent earthquakes are consequence of long-term tectonic phenomena, while triggered events are mainly attributed to stress changes caused by previous events. Hence the robust identification of earthquake clusters is crucial for understanding and forecasting the spatio-temporal evolution of earthquake sequences on a short time scale and it is pivotal for seismic hazard assessment. Two data-driven declustering algorithms based on stochastic point processes and nearest-neighbour distances were used by Bi et al. (2024) to decluster earthquake events of $M \geq 3.0$ in North China, exploring the sequence characteristics and its effect on the Gutenberg–Richter b value. They found that both algorithms are able to suitably remove the influence of significant earthquakes and perform similarly in terms of spatio-temporal declustering, sequence identification, and evolution of *b* value. In the same active area, Chen et al. (2024) examine the coseismic deformation field resulting from the January 8, 2022 Mw 6.7 Menyuan earthquake, which occurred along a major boundary fault zone in the north-eastern Tibetan Plateau (China). This region is characterized by a left-lateral strike-slip fault system, which is responsible for the occurrence of large earthquakes on a relatively frequent basis. The authors use Sentinel-1A InSAR data and further simultaneous inversion procedures to model the coseismic slip and, in addition, the near-field pixel offset data method to delineate the fault trace and constrain the deformation pattern, such as fault length and strike. Additionally, the study evaluates the interactions between the 2022 earthquake and historical events and, using newly GNSS-derived velocity field, the authors evaluate the geodetic-derived slip rate to evidence the interseismic coupling on the fault plane. The findings highlight the potential seismic hazard at the western end of the Tianzhu seismic gap. In the region of Mila, Algeria, Hamidatou et al. (2024) provide a comprehensive seismic hazard assessment focusing on the August 7, 2020 (Mw 5.0) earthquake. Using both probabilistic and deterministic seismic hazard analysis (PSHA and DSHA), the study estimates peak ground acceleration (PGA) and seismic intensity in the affected areas. The authors also integrate environmental factors, including landslides, rockfalls, and ground deformation, into the assessment through the Environmental Seismic Intensity (ESI) scale, providing a more nuanced understanding of the earthquake's effects. The analysis reveals significant variability in the PGA estimates, with DSHA yielding higher values than PSHA, and underscores the importance of considering site-specific conditions for accurate hazard evaluations. Additionally, the study highlights the relevance of the ESI scale in assessing environmental damage, which often surpasses traditional macroseismic scales in intensity. The findings emphasize the necessity of including environmental factors in seismic hazard assessments to improve predictions for future seismic events, particularly in seismically active regions like Mila. This interdisciplinary approach offers a valuable tool for future risk reduction strategies and building design in earthquake-prone areas. Moving on to Northeast India, Baruah et al. (2024) investigate how the 1897 Shillong earthquake caused extensive surface and subsurface damage in this area. In the western Shillong Massif, the event created land fissures, sand veins, and uplift. This study integrates seismic, geophysical, and fluvial geomorphology methods to quantify co-seismic ruptures. Using MASW and resistivity surveys at 14 locations across the Krishnai and Chedrang Rivers, researchers observed co-seismic uplifts of 5 ± 1 m and shear wave velocities of 184–466 m/s, highlighting intense shallow seismicity. Fluvial morphometric analyses from 1964 to 2014 revealed westward shifts of the Krishnai River (190–269 m) and southwestward avulsion of the Chedrang River (132–312 m). Stratigraphic mapping identified mega-thrust event evidence in fault scarp deposits. High-resolution topography showed deformation east of the rivers. The findings improve understanding of the region's seismic hazards and highlight the 1897 earthquake's long-term geodynamic impacts, aiding future hazard assessments. Pal et al. (2024) present a study of the Siang Valley in Arunachal Pradesh, India, which lies within the seismically active Eastern Himalayan Syntaxis (EHS). This study examines seismicity, fault plane solutions (FPS), and pressure (P) axis orientation in the region. An analysis of 756 local earthquakes (magnitude 1.0–5.9) from January 2019 to December 2021 reveals seismicity concentrated in Namcha-Barwa and the western and eastern flanks of the Siang Antiform, extending to depths of 60 km, primarily in the upper crust. Waveform inversions (ISOLA) is performed by the authors for 15 events (magnitude 3.5–5.9), using a frequency range of 0.01–0.1 Hz and optimal crustal velocity models. Results indicate predominantly normal faulting with strike-slip components for shallow earthquakes, while compressional axes of thrust FPS align northeast. The intense seismicity and P-axis orientations reflect the collision between the Indian and Eurasian plates and the eastward subduction of the Indian plate beneath the Burmese plate. By considering the European seismic context, Fernández-Fraile et al. (2024) perform a systematic re-evaluation of earthquakes in early twentieth-century Spain, a period with inconsistent data sources. Using diverse materials—reports, questionnaires, seismograms, newspapers, and photos—the research revisits 16 earthquakes from 1900 to 1962 in SE Spain, applying EMS-98 intensities and determining macroseismic epicenters, except for one instrumental case. Depth values were estimated for eight events, with focal depths generally under 10 km but with notable uncertainties. Revised I_{max} (maximum seismic intensity) values are typically lower than those in the IGN catalog, differing by 0.5°–2.5°, except for the Lorquí earthquake (1912), which is smaller by 0.5°. Most of the epicenters were also updated with changes between 1 and 41 km. The study provides a consistent seismic catalog of re-evaluated epicenters and intensities, offering a valuable reference for comparing early twentieth-century seismicity with earlier periods. The methodology, tested in SE Spain, can be extended to the broader Iberian Peninsula. In their search for a more precise microseismic source location and analysis, Wang and Lv (2024) present a new method for the accurate identification of P-wave initial arrivals. As it is well known, conventional algorithms struggle with low signal-to-noise ratio (SNR) microseismic data due to strong background noise. To address this, the method proposed by the authors combines variational mode decomposition (VMD) and sample entropy for denoising, followed by the pruned exact linear time (PELT) algorithm for arrival time determination. Compared to traditional approaches like the short-term average/long-term average ratio (STA/LTA) and Akaike information criterion (AIC) methods, this approach significantly improves picking accuracy and noise resistance, making it more effective for low-SNR microseismic data. In contrast, the in-depth analysis of Liu et al. (2024) proposes a multisynchrosqueezing-based S-transform methodology to improve the energy concentration of the time–frequency representation of seismic signals. The authors outline the mathematical formulation of the method, which involves multiple Synchrosqueezing S-transform operations to iteratively concentrate the time–frequency energy of a non-stationary signal. When compared with other methods, as short-time frequency transform, S-transform and Synchrosqueezing S-transform, the authors show that in addition to effectively enhance the time–frequency energy concentration the suggested methodology offers better performance in characterizing non-stationary signals. The authors discuss several synthetic examples, and also use field seismic data from a gas-filled reservoir in Songliao basin (China) to demonstrate the effectiveness of the proposed method in improving time–frequency resolution.

Geophysical exploration techniques based on potential fields offer valuable resources to investigate the characteristics of the Colorado River Delta in Baja California, México. González-Escobar et al. (2024), through 2D reflection seismic profiles and gravimetric anomaly maps, provide a detailed study of the lower crust structure of the Cerro Prieto and Pangas Viejas fault systems, which outline the Montague Basin. Their research identifies five major new faults, two regional structures resulting from subsidence to the west of the Cerro Prieto transform fault, and a regional structure to the west of the Pangas Viejas Fault. The study also reports for the first time an acoustic basement to the northeast of the Cerro Prieto fault, coinciding with a local gravimetric high, located in the Altar Basin area. A further significant finding is that the southern Colorado Delta is opening up and will eventually be invaded by the sea. The research sheds valuable insights into the understanding of pull-apart basins and the evolution of transfer faults between basins, as well as into the seismic risk in the region, providing a better understanding of the underlying factors and potential applications in other areas of the world. Using aeromagnetic anomalies, with a focus on the inversion of magnetic data to understand the subsurface volcanic structures, Ekinci et al. (2024) investigate the Kula Volcanic Field in western Turkey. The authors apply a novel global optimization algorithm, the Success-History-Based Adaptive Differential Evolution (E-SHADE), which incorporates an exponential population reduction strategy to improve computational efficiency. The algorithm is compared with local optimizers and shown to perform better in terms of accuracy and robustness. The study identifies shallow basaltic intrusions beneath the volcanic cones, suggesting that the region's three-phase volcanism may become active again, potentially generating new alkaline basaltic lava flows. The research also includes synthetic and field data inversions, demonstrating the algorithm's effectiveness in interpreting noisy magnetic data and providing geologically reliable parameter estimations. This work presents the E-SHADE algorithm as a powerful tool for geophysical inverse problems, offering improved results in comparison to traditional methods. The findings contribute to a better understanding of the Kula Volcanic Field and its potential for future volcanic activity.

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