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Venice, 1-2 March 2024

ABSTRACT BOOK

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X AIGeo Italian Young Geomorphologists' Day & III IAG International Young Geomorphologists' Meeting

"Climate change and the role of early-career geomorphologists"

Università Ca'Foscari Venezia
Dipartimento di Scienze Ambientali, Informatica e Statistica

COVER IMAGE:

An overhead view of the typical saltmarsh landscape (*barene*) of the Venice lagoon. The mudflats and grasslands of Salicornia Veneta, visible in the image, allow the maintenance of the landforms in the silty clay soils (Photo courtesy of A. Rovere).

X AIGeo Italian Young Geomorphologists' Day & III IAG International Young Geomorphologists' Meeting

"Climate change and the role of early-career geomorphologists"

Venice, 1-2 March 2024

The X AIGeo Italian Young Geomorphologists' Day and the III IAG International Young Geomorphologists' Meeting aimed to bring together emerging researchers investigating various morphogenetic and morphoclimatic environments. The goal was to foster collaboration among young geomorphologists utilizing specific methodologies tailored to each unique context. We highly encouraged participation of young geomorphologists all over the world to facilitate a rich exchange of ideas and foster scientific partnerships.

The events were promoted by AIGeo (Italian Association of Physical Geography and Geomorphology) and sponsored by the Department of Environmental Sciences, Informatics and Statistics (DAIS) of Ca' Foscari University of Venice under the auspices of the International Association of Geomorphologists (IAG). The events were held as part of the IAG International Geomorphology Week 2024.

They include both oral and poster scientific sessions, Equity, Diversity and Inclusion (EDI) discussion, the IAG Southern Europe Webinar, an urban field trip in the city of Venice and a social event called the "bacaro tour".

Mauro Bonasera, Claudia Caporizzo,
Ciro Cerrone & Chiara Martinello

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S1.

Coastal geomorphology

CONVENER & CHAIRPERSON

Giovanni Scardino (University of Bari Aldo Moro)

3D reconstruction of coastal sea floor morphology through two-media Structure from Motion-Multi-View Stereo using low altitude aerial photographs

Casella E.[1*], Lewin P.[2], Ghilardi M.[2], Rovere A.[1] & Bejarano S.[2]

[1] Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, Italy.
[2] ZMT, Leibniz Centre for Tropical Marine Research, Bremen, Germany.

Corresponding author e-mail: elisa.casella@unive.it

Keywords: sea floor 3D reconstruction, UAS, SfM-MVS, shallow coral reef, structural complexity.

The last years saw an exponential growth of the use of UAS (Unmanned Aerial Systems), in earth science. The low altitude – high resolution – aerial view offered by drones started to be regarded as a third-generation source of remote sensing data (Simic Milas et al. 2018), providing scientists new and accessible tools to explore the Earth surface. The concurrent advances in computer vision science facilitated accurate 3D reconstruction of realms captured by low altitude photographs thanks to the Structure from Motion and Multi-View Stereo reconstruction methods. These technological and scientific advances facilitate the collection of centimeter-resolution continuous data at relatively low cost with more flexibility in the survey design (e.g. Castellanos-Galindo et al. 2019; Casella et al. 2020). The 3D reconstruction of coastal sea floor morphology from aerial photographs sees many error sources since the light rays have to travel through two media (air–water) (Casella et al., 2017; Joyce et al. 2018; Casella et al. 2022). Here we present a study where the relative accuracy of reconstructed 3D features on the sea floor is investigated. The study took place in the Palau Archipelago, western Micronesia. Between November 2019 and February 2020 nine shallow water reefs have been surveyed with calm winds (less than 2 km h-1) and low wave motion. A consumer-grade UAS (DJI Phantom-4 Pro) was used to collect 980 near nadir photographs, covering a total area of 6830 m^2 across all reef sites. Digital surface models (DSM) of the sea floor were reconstructed for each site and independent measurements were collected to validate the ability of the method in reconstructing the vertical dimension of reconstructed corals.

Casella E., Collin A., Harris D., Ferse S., Bejarano S., Parravicini V., Hench J.L. & Rovere A. (2017) - Mapping coral reefs using consumer-grade drones and structure from motion photogrammetry techniques. Coral Reefs, 36, 269-275. https://doi.org/10.1007/s00338-016-1522-0.

Casella E., Drechsel J., Winter C., Benninghoff M. & Rovere A. (2020) - Accuracy of sand beach topography surveying by drones and photogrammetry. Geo-Mar Lett., 40, 255-268. https://doi.org/10.1007/s00367-020-00638-8.

Casella E., Lewin P., Ghilardi M., Rovere A. & Bejarano S. (2022) - Assessing the relative accuracy of coral heights reconstructed from drones and structure from motion photogrammetry on coral reefs. Coral Reefs, 41(4), 869-875.

Castellanos-Galindo G.A., Casella E., Mejia-Renteria J.C. & Rovere A. (2019) - Habitat mapping of remote coasts: Evaluating the usefulness of lightweight unmanned aerial vehicles for conservation and monitoring. Biol. Cons., 239, 108282.

Joyce K.E., Duce S., Leahy S.M., Leon J. & Maier S.W. (2018) - Principles and practice of acquiring drone based image data in marine environments. Mar. Freshw. Res., 70(7), 952-963.

Simic Milas A., Cracknell A.P. & Warner T.A. (2018) - Drones–the third generation source of remote sensing data. Int. J. Remote Sens., 39, 7125-7137.

Ongoing Multi-method Investigations of Last Interglacial Sea Level

Dean S.[1*], Chauveau D.[1], Cerrone C.[1], Georgiou N.[1], Ryan D.D.[2], Rubio-Sandoval K.[3] & Rovere A.[1]

[1]Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, Italy.
[2]Department of Earth Sciences, University of Pisa, Italy.
[3]MARUM - Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany.

Corresponding author e-mail: silas.dean@unive.it

Keywords: sea floor 3D reconstruction, UAS, SfM-MVS, shallow coral reef, structural complexity.

The Last Interglacial (LIG, Marine Isotope Stage 5e, ~125 ka) is a process analogue for a future warmer climate. Thousands of coastal relic landforms and deposits dating back to this period are studied today to obtain insights on pressing questions such as: What was the peak LIG sea level? Was the highstand characterised by single or multiple peaks? Were rapid sea-level changes triggered by sudden ice sheet collapses? The WARMCOASTS project has already compiled a large database of LIG sea-level proxies in the World Atlas of Last Interglacial Shorelines (WALIS), and investigation is also continuing using a number of methods including coral reef stratigraphic forward modelling, storm event and wave modelling, and field surveys for sea-level indicators in South and North America and the Caribbean. The results of this ongoing research may help refine our understanding of ice sheets and sea levels under warmer climate conditions.

Geomorphic aspects of the beaches of the volcanic Island of Procida, southern Italy

Ilacqua S.[1*], Lämmle L.[2] & Donadio C.[3]

[1]Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra (MIFT), Università degli Studi di Messina.
[2] Institute of Geosciences, University of Campinas (UNICAMP, São Paulo, Brazil).
[3]Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR), Università degli Studi di Napoli Federico II.

Corresponding author e-mail: silviailacqua@hotmail.it

Keywords: coastal geomorphology; marine sediments, littoral erosion, Italy.

This research focuses on the geomorphological and morphosedimentary analysis of the two largest and most popular beaches of the volcanic island of Procida in the Mediterranean Sea in the context of the smaller islands. The smaller islands represent a natural and tourist heritage of great importance. Still, they are also strongly influenced by ongoing global climate changes that pose several challenges to their protection (IPCC, 2021). To understand their coastal dynamics, we analyzed the weather-marine conditions, morphometric, granulometric, and morphoscopic characteristics of the emerged and submerged beach to obtain information detailed on the classification of sediments, the genetic-depositional environment and the morphological evolution of the coasts studied. Furthermore, samples of the submerged beach were collected to define the coastal dynamics for the first time. Through geomorphological surveys, were also drawn up coastal geomorphological maps for the emerged and submerged areas of the analyzed beaches. The research fits into the broader context of coastal planning, contributing to understanding the erosive and morphodynamic processes underway. The littorals analyzed are pocket beaches: their coastlines are attractive for tourism, representing significant economic resources for the smaller islands. Therefore, concerns emerge regarding the high erosion of these beaches, with an imminent risk of disappearance within a few years. In this sense, the research takes on relevance from the perspective of ongoing climate change and the challenges associated with the sustainable management of coastal resources. This last point is crucial if the two beaches fall within the Marine Protected Area Regno di Nettuno. Mitigating coastal erosion in the marine protected areas represents a challenge to preserve sensitive marine ecosystems and ensure the conservation of these precious natural resources. This aim requires a detailed understanding of the coastal system and the integration of effective but low-impact solutions toprotect without compromising marine habitats. To address this situation, based on the case study in question, we propose implementing sustainable and environmentally friendly mitigation techniques that carefully consider the peculiarities of each beach analyzed and the presence of the marine protected area.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Coastal erosion and mitigation solutions for the coast of the Paraíba do Sul and Jequinhonha river delta (Brazil)

Lämmle L.[1*], Perez Filho A.[1], Donadio C.[2] & Avramidis P.[3]

[1]Institute of Geosciences, University of Campinas, Brazil.
[2]Department of Earth Sciences, Environment and Resources, University of Naples Federico II, Italy.
[3]Department of Geology, University of Patras, Greece.

Corresponding author e-mail: l211619@dac.unicamp.br

Keywords: coastal erosion, transition environments, fluvial-marine dynamics, connectivity.

Since the 1950s, around 90% of the world's coastlines have been eroding, 5% are stable and only 5% are progressing, with varying intensities from one area to another due to natural and anthropogenic factors. In Brazil, problems associated with coastal erosion have been increasingly reported, especially in transitional environments (such as coastal plains, deltas and estuaries), which are even more sensitive areas due to the interaction between river and marine dynamics. On the coast of the coastal plain of the river Paraíba do Sul and Jequitinhonha (Brazil), this process reached a critical level and became a social problem, with the relocation of families whose homes were invaded by the sea, loss of tourist attractions and worsening in environmental quality. In this sense, based on a systemic approach, this work aims to understand this process using qualitative and quantitative methods based on multi-scale mapping from orbital and non-orbital images, analyzing the hydro-sedimentary dynamics over time of the river basins, and its relationships with changing coastlines over the last 50 years. With this, we intend to demonstrate the progressions of changes in the coastline in position and area, identify their causes based on qualitative analysis associated with land use in the basins and indicate possible mitigating solutions that are economically viable to be adopted for each area.

On the banquette dynamics in an urban microtidal Mediterranean beach (Poetto beach, southern Sardinia, Italy) by a four-years coastal videomonitoring images database analysis

Trogu D.[1*], Simeone S.[2], Porta M.[1], Ruju A.[3] & De Muro S.[1]

[1]Coastal and Marine Geomorphology Group (CMGG), Dipartimento di Scienze Chimiche e Geologiche Università degli Studi di Cagliari, Cittadella Universitaria, 09042 Monserrato, Italy.
[2]IAS – CNR – Località Sa Mardini – Torregrande 09170 Oristano.
[3]Dipartimento di Ingegneria Civile, Ambientale e Architettura, Università di Cagliari, Via Marengo 2, 09123, Cagliari.

Corresponding author e-mail: d.trogu@unica.it

Keywords: banquette, Posidonia oceanica, videomonitoring, beach morphodynamics, Mediterranean Sea.

The present work is part of the research activities on coastal areas carried out by the Coastal and Marine Geomorphology Group, belonging to the Department of Chemical and Geological Sciences of the Cagliari University, and deals with issues related to the resilience of Mediterranean microtidal beaches in the climate change scenario. The data collection was made possible by the NEPTUNE Project (*Natural Erosion Prevision Through Use of Numerical Environment*), which provided the measurement network, while the RETURN Project (*multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate*) made the data processing possible.

The deposition and sedimentation of seagrasses on Mediterranean beaches is a very common phenomenon. These deposits, known as banquettes, are mostly composed of leaves, roots, and rhizomes of *Posidonia oceanica* (L.) Delile, mixed with sediment. For this study (Trogu et al., 2023), a four-year images database coming from a high-resolution videomonitoring station installed above the promontory of an urban, microtidal and wave dominated beach, located in the Gulf of Cagliari, Italy, western Mediterranean has been analysed, from September 2016 to September 2020. By orthorectifying the images, the daily cross-shore extent of the banquettes was measured in three transects of the beach and then their daily difference in cross-shore amplitude was correlated with wave and wind parameters (obtained from the Copernicus and ERA5 databases). The results show that banquette deposition is closely related to the presence or absence of floating leaf litter in the surf zone. Analysis of wave parameters indicate that deposition occurs during mild storms, while banquette erosion occurs during more intense storms. The presence or absence of these biomasses in the surf zone can therefore also explain the low correlation value found between the individual wave parameters and the cross-shore width of the banquette, as well as with its daily difference.

The dynamics of banquettes are also affected secondarily by offshore winds: when no obstacles are present and under certain conditions of wind speed, the banquette may be removed offshore, supplying the litter in the surf-zone, or they may be buried by sand, building a sedimentary berm composed by vegetal rests and sand, that can also increase the beach resilience against the storms, due to its high permeability. The permanence of these berms on the beaches also depends on their composition: when banquettes are intertwined with reeds, their removal by the waves does not occur even during intense storms and this sedimentary structure can protect the beach from flooding.

Trogu, D., Simeone, S., Ruju, A., Porta, M., Ibba, A. & DeMuro S. (2023) - A Four-Year Video Monitoring Analysis of the Posidonia oceanica Banquette Dynamic: A Case Study from an Urban Microtidal Mediterranean Beach (Poetto Beach, Southern Sardinia, Italy). JMSE, 11, 2376. https://doi.org/10.3390/jmse11122376.

Rocky coastal evolution linked to climate change processes

Tursi M.F.[1*], Mattei G.[1], Manno G.[2], Anfuso G.[3] & Aucelli P.P.C.[1]

[1] University of Naples "Parthenope", Italy.
[2] University of Palermo, Italy.
[3] University of Cadiz, Spain.

Corresponding author e-mail: mariafrancesca.tursi001@studenti.uniparthenope.it

Keywords: Rocky coast, susceptibility index, coastal evolution, South Italy.

Rocky coasts represent the most widespread coastal environment and, under the present accelerated sea-level rise scenario, are suffering huge impacts in terms of erosion. They constitute a "work in progress" landform, i.e. a morphology affected by a wide range of marine and terrestrial processes that continually reshape it through time. In view of this, the aim of this research is the proposal of a new methodological approach for the assessment of rocky coasts susceptibility to erosive processes under the effects of the ongoing climate change. The proposed method is based on the combination of two matrices, i.e., the Physical Element Index (PEIx), which considers the main morphological and geotechnical characteristics of the landform and determine its proneness to erosion, and a Cliff Forcing Index (CFIx), which describes the marine forcing agents affecting the considered coastal form. Firstly, several variables were selected to construct the two matrices according to existing studies. Then, the variables were weighted with factors (Wfi) according to their relative importance in determining the total cliff erosion susceptibility and forcing impact. In the second step, the two matrices were interpolated to obtain the final Susceptibility Index (CSIx). The approach was applied to different coastal sectors located along the Southwest coasts of Italy, differing from each other in geological settings and marine characteristics. The analysis shows that 50% of the considered cliff belongs to the low susceptibility class, 25% belongs to the medium susceptibility class and the remaining 25% belongs to the high/very high susceptibility class mainly due to the combination of adverse morphological, geotechnical, and forcing characteristics. In a further step, the obtained susceptibility index for each coastal stretch was validated by comparing it with the cliff retreat rate derived from the analysis of aerial photographs and satellite images. Results of this validation show an acceptable correlation between the predicted values and the obtained results, with ca. 65% of the variation in the CSIx coinciding with the measured retreat rates. In conclusion, the results point attention on the key role played by lithology and by the degree of exposure of the considered sector to wave events, being the increase of extreme events one of the most dangerous consequences of climate change. Therefore, sectors showing a high value of susceptibility can be considered "hotspots" requiring an increase in monitoring programs and, at places, urgent protective actions

Combined emergent and submerged 3D models to study rocky coasts: Which perspective for climate studies?

Vaccher V.[1], Corradetti A.[1] & Furlani S.[1]

[1]Department of Mathematics, Informatics and Geosciences, University of Trieste, Italy.

Corresponding author e-mail: valeria.vaccher@gmail.com

Keywords: Photogrammetry, 3D models, Mediterranean, Geomorphological Landforms, Sea Level Changes.

Terrestrial and underwater photogrammetry are widely used to build 3D models of emergent and submerged coastal objects. Recently, some authors also investigated approaches and methods to collect data and reconstruct partially submerged objects (e.g., Nocerino et al., 2019) and the tidal and nearshore zone of long sectors of rocky coasts in the Mediterranean Sea (e.g., Furlani et al., 2021). The combined analysis of these two datasets (emergent and submerged photogrammetry-derived models) is generally complicated by technical and environmental limitations. This work aims at analysing these limitations starting from three case studies in the Mediterranean area. Georeferenced and scaled 3D models have been produced for integrating emergent and submerged geomorphological objects and to obtain morphometric parameters of specific landforms related to sea level changes, such as tidal notches, bioeroded holes, etc. Images were collected within the framework of the Geoswim programme (Furlani, 2020), employing an ISR (Instrumental-Supported Raft), a raft-based survey methodology pushed on the water surface, captures data, including time-lapse images used in this context.

The resulting models are geolocalized in time and space, scaled and measurable, allowing the users to describe in detail the morphometric parameters coastal landforms related to past sea levels. The merging of the models above and below the waterline highlights some technical issues due to the physical characteristics of air and water, such as density, temperature, and pressure. Moreover, the illumination conditions and the different refractive indices occasionally complicated underwater photogrammetry.

In the end, integrated models represent an intriguing challenge for coastal and sea level change studies. The integrated photogrammetry-derived 3D models represent a promising avenue for advancing coastal and sea level change studies.

Furlani S., Vaccher V., Antonioli F., Agate M., Biolchi S., Boccali, C., Busetti A., Caldareri F., Canziani F., Chemello R., Causon Deguara J., Dal Bo E., Dean S., Deiana G., De Sabata E., Donno Y., Gauci R., Giaccone T., Lo Presti V., Montagna P., Navone A., Orrù P.E., Porqueddu A., Schembri J.A., Taviani M., Torricella F., Trainito E. , Vacchi M. & Venturini E. (2021) - Preservation of modern and MIS 5.5 erosional landforms and biological structures as sea level markers: a matter of luck? Water. 13, 15, 2127.

Furlani S. (2020) - Integrating observational targets and instrumental data on rock coasts through snorkel surveys: A methodological approach. Marine Geology, 425, 106191.

Nocerino E., Menna F., Farella E., Remondino F. (2019) - 3D virtualization of an underground semisubmerged cave system. Int. Arch. Photogramm. Remote Sens., 42, 857-864.

S2.

Glacial and periglacial geomorphology

CONVENER & CHAIRPERSON

Stefano Ponti (University of Insubria)

Glacial and periglacial landscape in Turkey: from the flood to anthropic geomorphology

Azzoni R.S.[1*], Sarıkaya M.A.[2], Pelfini M.[1], Pezzotta A.[1], Bollati I.M.[1] & Zerboni A.[1]

[1]Dipartimento di Scienze della Terra "A. Desio", Università degli Studi di Milano, Milan, Italy.
[2]Eurasia Institute of Earth Sciences, Istanbul, Technical University, Istanbul, Turkey.

Corresponding author e-mail: robertosergio.azzoni@unimi.it

Keywords: glacial geomorphology, remote sensing, Mediterranean glaciation, Anatolia, volcanic geomorphology.

Considering the accelerating glaciers retreat observed worldwide, the knowledge of the state of glaciation and the dynamics of deglaciation is fundamental to understand the effect of climate change. The circum-Mediterranean glaciated areas are among the most sensitive parts of the Planet rapidly reacting to ongoing glacier melting. The Turkish glaciers inventory finalized in 2020, based on high-resolution satellite images (Pleiades, Google Earth™ and SPOT images) allowed the identification of 51 active glaciers covering 12.29 km^2. Turkish glaciation is characterized by small glaciers or glacierets partly debris-covered located in small cirques and valleys. Geodiversity of glacial landforms and related proglacial areas are very significant and explained with two iconic examples: the Mt. Ararat and the Cilo Mountain range. As a single site, more than 60% of the Turkish glacierized area is located on Mount Ararat (where an ice cap and 4 small outlet glaciers cover an area of 7.37 km^2. On Mount Ararat, we digitized outlines for 1990, 1994, 2000 and 2016: in a 26 years interval (1990-2016), the glacier shows a retreat of 2.99 km^2, equal to 29% of the initial value, showing a reduction rate dramatically higher than the main glacierized mountain ranges of the world. Therein, in-situ geomorphological investigation and remote-sensing analyses also reconstructed a dramatic lahar event occurred in the Ahora Gorge in 1840. In the same area, we identified and described a glacier originates after this catastrophe, and never mapped before. Moreover, we realized a geomorphological map on Cilo Mountain range, another representative glaciated sector of Turkey for illustrating the main landforms related to the paraglacial transformation affecting the proglacial area. Finally, we investigate the glacier evolution and the periglacial features of Mount Erciyes (Cappadocia) where the glacial landscape has changed rapidly due to the ongoing climate change and to the strong anthropic: this massif is the largest ski resort of Turkey and the development of ski slopes affects the hydrology and subsequently alters the geomorphic processes of the area.

Conservation of World Heritage glacial landscapes in a changing climate: The Swiss Alps Jungfrau-Aletsch case

Bussard J.[1*]

[1]Institute of Geography and Sustainability, Interdisciplinary Centre for Mountain Research, University of Lausanne, Switzerland. Swiss Geomorphological Society, representative of the Young Geomorphologists.

Corresponding author e-mail: jonathan.bussard@unil.ch

Keywords: glacial landscape, climate change, geoheritage, post-glacial future.

Many glacial landscapes on all continents are inscribed on the World Heritage List. Due to climate change, most of the glaciers are retreating rapidly, thus questioning their Outstanding Universal Value (OUV). Ice loss could indeed reduce or modify the heritage values of the UNESCO World Heritage properties where glaciers are the core of the OUV and even question their inscription on the World Heritage List. In a future with fewer or without glaciers, at least two components of the OUV of World Heritage glacial landscapes could be affected: the aesthetic value (criterion *vii*), which could be reduced if glaciers disappear, and the geoheritage value (criterion *viii*), which is partly based on current glaciological processes that would no longer exist without ice. This presentation aims to clarify what constitute the heritage values of glacial landscapes and outlines how they could evolve in a future with less (or without) ice. For two sites in the UNESCO Swiss Alps Jungfrau-Aletsch property (the Great Aletsch Glacier and the Upper Lauterbrunnen Valley), we describe the evolution of the glacial landscape using a Past-Present-Future framework. We then evaluate the present and post-glacial heritage values according to criteria used in the literature on geomorphosites. We outline two main issues: (1) The two sites are characterized by a very high palaeogeographical interest: the inherited glacial landforms around the Great Aletsch Glacier and Lake Oberhorn have allowed the reconstruction of Holocene glacial stages. In the future, the inherited landforms of high palaeogeographical interest and the para- and periglacial processes that develop in post-glacier conditions are likely to gain interest, while the dynamics of the glacier itself, which is an important part of the current geoscientific value, will decline and even be lost when the glacier disappears. As glaciers retreat, the geoscientific value will therefore depend more and more on the inherited glacial landforms, which allow the understanding of the Earth and climate history, and less and less on the glacier itself and its dynamics. As the inherited landforms can be fragile, are non-renewable and will become more central to the heritage value, their protection is an issue. (2) The aesthetic value of glacial landscapes could decrease because of the disappearance of the glacier (landscape greying). One possible adaptation could be a shift from glacier tourism, which is mainly oriented towards the contemplation of an aesthetic landscape, to geotourism, where the understanding of landscape evolution is proposed to the public.

Geomorphological approach to Satellite Data Analysis: A Case of Study in Deglaciated Alpine Areas (Gran Paradiso Group, Italian Western Alps)

Cerrato R.[1*], Gennaro S.[2], Salvatore M.C.[1,2], Salzano R.[3], Salvatori R.[4] & Baroni C.[1,2]

[1]Earth Sciences Department, University of Pisa, Via S. Maria 53, 56126 Pisa, Italy.
[2]Institute of Geosciences and Earth Resources, National Research Council of Italy (IGG–CNR), Via G. Moruzzi 1, 56124 Pisa, Italy.
[3]Institute of Atmospheric Pollution Research, National Research Council of Italy (IIA–CNR), Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy.
[4]Institute of Polar Sciences, National Research Council of Italy (ISP–CNR), 00010 Montelibretti,

Corresponding author e-mail: riccardo.cerrato@unipi.it

Keywords: NDVI, spectral signature, lateglacial, Egesen, Little Ice Age.

The ongoing climate warming is deeply altering high-elevation environments, resulting in a reduction of glacier and snow covers and causing a widespread greening phenomenon across Alpine regions. However, assessing the greening rate could be challenging, resulting in noisy time-series when highly dynamic environments such as high elevation areas are considered on a large scale (e.g., valley, regions). A comprehensive impact assessment necessitates a holistic approach, integrating the geomorphological context with altitudinal and ecological characteristics to contextualize observed changes. The proposed study uses deglaciated and chronologically constrained areas as geomorphological indicators to investigate greening differences within both alpine and non-alpine ecological belts. Our investigation focuses on the Gran Paradiso Group in the Italian Western Alps, specifically targeting protected and minimally anthropogenic-impacted regions. The use of Landsat time series, characterized by long-term analysis and medium spatial resolution (30 m), emerged as a valuable asset for characterizing vegetation in high-elevation areas undergoing significant climate-induced transformations at the valley scale. Our results indicate an overall and ongoing greening process across the entire study area, with greening rates inversely correlated with elevation. The analysis of Landsat Normalized Difference Vegetation Index (NDVI) time series between 1984 and 2022 reveals a progressive greening trend even at higher altitudes, although not uniformly distributed. Interestingly, non-alpine (ecological *sensu*) bare rock areas deglaciated since the Egesen (11–13 ka) do not comply with this pattern, whereas spectral reflectance analyses unveil a consistent decline over time on recently deglaciated surfaces, indicating the progressive colonization. These differences in ongoing greening processes in deglaciated Alpine areas can be explained considering the geomorphological behaviour of the investigated area. The combined use of satellite data processing and geomorphological selection criteria based on exposure times greatly improved the comprehension of greening within deglaciated areas of the Alpine regions allowing for a more accurate trend analysis. Preliminary observations indicate an increase in vegetation cover or increased biomass accumulation over time, but with a significant conditioning driven by the landforms' evolution. Quantitative assessments are needed, also considering that the recent deglaciation provided an opportunity to examine the evolution of vegetation colonization and succession. Notably, the observed NDVI trends highlight the local factors influencing greening in lower-elevation areas, pointing out the complex interaction of environmental variables. The geomorphology-driven selection of deglaciated areas proved to be a potent tool to contextualize climate changes impacts in particularly dynamical landscapes like high mountain regions.

The Last Glacial Maximum in the Orobic Alps (Lombardy, Italy): Combining ELA modelling and landform analysis

Rettig L.[1*], Mozzi P.[1] & Monegato G.[2]

[1]Department of Geosciences, University of Padova, Padova, Italy.
[2]CNR IGG, Padova, Italy.

Corresponding author e-mail: lukas.rettig@phd.unipd.it

Keywords: Equilibrium Line Altitude, Glacial geomorphology, Glacier modelling, Last Glacial Maximum, Surface exposure dating.

Correctly estimating the extent and ice volume of former glaciations is important for a number of reasons such as for reconstructing climatic fluctuations, meltwater availability, or sediment transport. Palaeoglaciers are usually reconstructed through (field) mapping of glacial sediments and landforms, preferably in combination with a numerical dating method that provides the chronological framework. This approach, however, can be time- and resource consuming if a glacier reconstruction over larger spatial areas is attempted. An alternative method was presented by Spagnolo & Ribolini (2019) who proposed to use geomorphological evidence from one (or few) sites to calculate a regional glacier Equilibrium Line Altitude (ELA) from which then glaciers in other catchments can be modelled. Here, we present a reconstruction of the Last Glacial Maximum (LGM) ice extent in the Serio and Brembo catchments (Orobic Alps, Lombardy, Northern Italy) based on the approach by Spagnolo & Ribolini (2019). First, we carry out a detailed reconstruction of the geometry and ELA of the LGM palaeoglacier in the Inferno Valley. The advance of this glacier is constrained by a prominent frontal-lateral moraine complex, which has been chronologically correlated to the LGM thanks to ^{36}Cl surface exposure ages from four erratic boulders. Based on the ELA estimate from the Inferno Valley, we then model the LGM glacier extent and ice volume across the whole Orobic Alps and compare the results of the reconstruction with independent sedimentological and geomorphological evidence. We find that for several catchments, the reconstructed glacier fronts are close to the locations of glacial sediments and/or frontal moraine ridges. This demonstrates that these sediments and landforms can likely be correlated to LGM glacier advances. Combining ELA modelling with landform analysis can be a powerful tool to reconstruct ice extent over larger spatial scales and to guide future field work campaigns.

Spagnolo M. & Ribolini, A. (2019) - Glacier extent and climate in the Maritime Alps during the Younger Dryas. Palaeogeography, Palaeoclimatology, Palaeoecology, 536, 109400, https://doi.org.10.1016/j.palaeo.2019.109400.

Assessing water and sediment dynamics in high mountain catchments undergoing paraglacial evolution through hydrometric monitoring and Satellite images: the Alpe Veglia case study (Central-Western Alps, Italy)

Tronti G.[1]*, Bollati I.M.[1], Comiti F.[2], Andreoli A.[3], Mao L.[4], Testa B.[5], Aldighieri B.[5] & Pelfini M.[1]

[1] Dipartimento di Scienze della Terra "A. Desio", Università degli Studi di Milano, Italia.
[2] Università degli Studi di Padova.
[3] Facoltà di Scienze agrarie, ambientali e alimentari, Libera Università di Bolzano.
[4] Department of Geography, University of Lincoln, UK. [5] CNR – IGAG, Milano.

Corresponding author e-mail: gianluca.tronti@unimi.it

Keywords: Proglacial areas, Sediment Connectivity, Hysteresis, Digital Photogrammetry.

Proglacial areas represent hot spots of geomorphological dynamism and sediment delivery. Assessing the magnitude of changes in such areas requires the integration of different kinds of quantitative data. In 2021, a multiparametric station was installed to collect data along the Rio Aurona, which drains the western portion of the Alpe Veglia catchment (NW Italy), where the glaciers coverage represents ~ 5%. Impressive quantities of unconsolidated sediments characterize the relative proglacial areas, which show signs of permafrost degradation, slope instabilities, and water-related erosive processes. The probe records different meters: the Hydrometric Level (L; m) a proxy of the discharge (Q; m^3*s^{-1}). The Electric Conductivity (EC; $\mu S*cm^{-1}$) and the water temperature (°C), proxies of the dissolved salts and of the different water sources and paths. The turbidity (NTU) to derive the NTU-Suspended Solid Load relation. Rainfall values (mm) were used to combine the hydrometric and meteorological information. Different relations among variables (Q-SSL, Q-EC) were analysed to characterize the ablation period at a monthly scale. Moreover, automatic algorithms were used to detect each hydrometric event, deriving hysteresis indexes between an independent (Q) and two dependent variables (EC and SSL). To provide an independent proxy of water and sediment sources and assess the ablation period through and between the monitoring seasons, we used the snow/ice cover trends, derived through the NDSI index of Sentinel-2 images. Combining all the data, we aim to assess the evolution trend of the Aurona catchment by monitoring the related water and sediments' paths. These first 2 monitoring years (2021-2022) show ablation periods highly influenced by the spring snow abundance (i.e., snowmelt period) where the riverbed, the riverbanks, and the nearest slopes represent the main sediment sources. The glacier melt periods follows the previous one, characterized by an increasing sediment transport efficiency and progressive exhaustion of the nearest sediment sources, in favour of the farthest ones (such as the proglacial areas). The recession period (late summer) is marked by a general sediment exhaustion of the farthest sources, with a stochastic renewing of the nearest one. Ongoing analyses (geomorphological mapping, Digital Photogrammetry) will allow to distinguish among sediment stores and sources, pairing the denudation and transport information through the ablation periods, providing future trends for the evolution of the area.

Role of Geospatial Technology in fostering Alpine ecological Study: An observation from the Central Himalaya, India

Reza M.[1*] & Joshi R.C.[2]

[1]Research Scholar, Department of Geography, Kumaun University, Nainital, India, 263001.
[2]Professor, Department of Geography, Kumaun University, Nainital, India, 263001.

Corresponding author e-mail: masoomreza@kunainital.ac.in

Keywords: Tree Island, LST, Glacier Basin, Tree Species, Corona.

Receding of glaciers and exposing morainic landscape is a global climatic phenomenon. It varies from altitude to altitude in the Himalaya and also basin to basin. Increase in temperature, changes the Himalayan landscape manifesting the shrinking of cryosphere. Exposed landscape and changing climatic conditions boosting the growth of trees in the patches, where ecological niche is becoming more suitable. This study is carried out using remote sensing data of 1974-2022 followed by ground validation and analysis of temperature data. The increase of tree patches or tree islands are observed in glacier basins demarcated in the area. The species found are *Pinus wallichiana*, *Juniperus communis L* and *Rhododendron campanulatum etc*. The treeline demarcation is validated using GEDI LIDAR tree height and Remote sensing canopy cover data.

S3.

Geomorphological tools and mapping

CONVENER & CHAIRPERSON

Gabriella Raffa (University of Pisa)

The geomorphodiversity index as a key parameter for the landscape management

Burnelli M.[1*], Alvioli M.[2] & Melelli L.[1]

[1]Department of Physics and Geology, University of Perugia, Perugia, Italy.
[2]Istituto di Ricerca per la Protezione Idrogeologica, Consiglio Nazionale delle Ricerche, Via Madonna Alta 126, 06128, Perugia, Italy.

Corresponding author e-mail: martina.burnelli@studenti.unipg.it

Keywords: Geomorphodiversity, Geodiversity, GIS, Terrain classification, Spatial analysis, Digital Elevation Model, Ecodiversity.

The quantitative approaches to assess geomorphodiversity have the potential to investigate the variety of landforms and morphological processes characterizing the landscape at different scales and in a simple and reproducible way. This avancement represent a relevant step for several applications the Earth Sciences, concerning land use management, as long as ecodiversity conservation and geoheritage. The recent methodology proposed by Burnelli et al. (2023) defines the land surface diversity (GmI) considering as input parameter the lithology, the slope angle, a geomorphological classification of the topographic surface and a drainage information. The resulting index is connected to the geomorphological diversity of areas with large topographic variability and flat areas. Compared to previous methods, the GmI introduces an innovative landforms assessment, and perform its morphometric analysis of landforms within specific physiographic units with homogeneous characteristics. The index has been validated against geomorphological maps, in selected locations, as long as in other regions and contexts. When compared with the local land use, the GmI can results as an interesting tool for the management of the territory, mainly to avoid the possible consequence of extreme events due to the climate change emergency. This methodology may help to understand the temporal and spatial evolution of the territory and to prevent the loss of geodiversity due to human activities caused by anthropization. In a broader context, the evidence supporting the inherent connection between the geosphere and the biosphere, encourages the use of this quantitative approach also to investigate the relationship between these two compartments, towards the safeguard of ecodiversity.

Burnelli M., Melelli L. & Alvioli M. (2023) - Land surface diversity: A geomorphodiversity index of Italy. Earth Surf. Proc. Landf., 48, 3025-3040, https://doi.org/10.1002/esp.5679.

Identification of river channel bankfull geometry from topographic indicators extracted from high-resolution digital elevation datasets

Delchiaro M.[1], Ruscitto V.[1], Schwanghart W.[2], Brignone E.[1], Piacentini D.[1] & Troiani F.[1]

[1]Sapienza University of Rome, Department of Earth Sciences, Rome, Italy.
[2]Institute of Earth and Environmental Science, University of Potsdam, Germany.

Corresponding author e-mail: michele.delchiaro@uniroma1.it

Keywords: Bankfull stage, Bankfull discharge, MATLAB functions, LiDAR, Hydraulic hazard.

River channel bankfull geometry and discharge are important features providing valuable insights into fluvial monitoring and flood recurrency. The bankfull stage represents the riverbank position that approximates the level at which water overflows onto the floodplain. Bankfull discharge is considered the channel-forming discharge, with a recurrence interval of approximately 1.5 years. Bankfull floods are significant, as they are highly effective in changing channel shape and characteristics. Their recurrence intervals can be used for stream assessment and have implications for infrastructure design and flood mapping. Additionally, gaining insights into the factors influencing floodplain inundation across various time periods is crucial, as the frequency of flood events is predicted to rise with the increase in global temperatures. In this contribution, we present a novel approach to identify the bankfull geometry through a set of dedicated MATLAB functions. A Digital Elevation Model (DEM) with ground resolution of 1 m/pixel is used as input elevation dataset, obtained with airborne LiDAR (Light Detection and Ranging) survey. The selected river channels are divided in regularly spaced sampling sections, where the bankfull geometry is extracted. Then, the hydraulic depth function that plots the elevation above the river thalweg vs. the ratio between the area and the width is computed for every section. Then, the elevation above river associated to the lowest and the most prominent peaks of the function, corresponding respectively to the bankfull stage or bankfull/floodplain inflection point and to the floodplain, are automatically extracted for each section. Manning's equation is then applied to the hydraulic geometry corresponding to the lowest peaks elevation to compute the bankfull discharge at every river channel section. The validation process includes the comparison between the results obtained through the automatic bankfull geometry and discharge estimation and discharge data available from river hydrological gauges. Results demonstrate that the developed approach is effective to delineate the bankfull geometry from high-resolution DEMs and complements traditional qualitative field observations. Thus, our approach represents a cost-effective alternative for mapping detailed spatial variations over large spatial extents that are difficult to cover with traditional fieldwork.

3D mapping of karst caves using GeoSLAM technology: potentials and challenges

Domazetović F.[1*], Lončar N.[1] & Šaban M.[2]

[1]Center for geospatial technologies, Department of Geography, University of Zadar.
[2]Public institution "Velebit Nature park".

Corresponding author e-mail: fdomazeto@unizd.hr

Keywords: karst caves, 3D mobile mapping, touristic caves (Modrič, Biserujka, Vrlovka).

Caves are among the most common karst features within the Dinaric karst of Croatia, although only a few dozen (around 20) are currently valorized for touristic purposes. Due to the complexity of their morphology, 3D mapping and inventorying of caves often pose a significant challenge. However, detailed 3D mapping is crucial for sustainable management of touristic caves, as it allows better understanding and supervision of a cave geomorphological characteristics and potential vulnerability. Traditional cave mapping is a lengthy and demanding process, which often results in insufficiently accurate or even false representations of cave morphology. Furthermore, existing traditional methods require prolonged and extensive speleological surveys. To increase the efficiency of 3D mapping, traditional methods are gradually being replaced by various geospatial technologies. This study examines the potentials and challenges for application of GeoSLAM technology for detailed mobile 3D mapping of selected karst caves of varying morphological complexity (length, depth, volume, etc.). Detailed 3D mapping was carried out for three selected touristic karst caves: Modrič Cave near Rovanjska (Croatia), Vrlovka Cave near Kamanje (Croatia) and Biserujka Cave at Krk Island (Croatia). 3D mapping of these touristic caves was performed with the Zeb Revo GeoSLAM device. Special focus was given to the different challenges encountered during the application of GeoSLAM technology for 3D mapping of the mentioned karst caves, as well as difficulties that occurred during the processing of a large amount of collected data. Based on the carried 3D mapping, detailed high-resolution 3D models of selected karst caves were created, from which selected morphometric features were calculated. Given that the mapped karst caves are valorized for touristic purposes, the possibilities for application of created 3D cave models for creation of promotional and educational materials, as well as for monitoring of morphological changes (damage) are discussed. Thanks to its high mobility, fast collection of dense point cloud, and high accuracy, GeoSLAM technology has shown great potential for detailed 3D mapping of complex karst caves.

Reconstructing the History of Rock Avalanches in Val Viola, Upper Valtellina, Italian Central Alps: Insights from 10Be Exposure Ages, Schmidt Hammer R Values, and Surface Roughness

Longhi A.[1]*, Morgan D.[2] & Guglielmin M.[1]

[1]Department of Theoretical and Applied Sciences, Insubria University, Varese, Via J.H. Dunant, 3, 21100, Italy.
[2]Department of Earth and Environmental Sciences, Vanderbilt University, Nashville, TN, USA.

Corresponding author e-mail: alessandro.longhi@uninsubria.it

Keywords: Paraglacial, Rock Avalanche, Holocene, Italian Alps, Permafrost.

We conducted an investigation into the paraglacial evolution and permafrost degradation of Val Viola in the Upper Valtellina of the Central Italian Alps, employing a comprehensive approach involving geomorphologic surveys, cosmogenic dating, Schmidt's Hammer analysis, and surface roughness measurements. Our findings indicate that the previously identified rock avalanche in Val Viola likely comprises three distinct events that occurred at 7.7±0.2 ka (Orthogneiss_1), 7.0±0.2 ka (Paragneiss), and 5.0±0.3 ka (Orthogneiss_2). Considering that the primary valley bottom has been ice-free since at least 12.6 ka, it appears improbable that the debutressing stress from the melting of local valley glaciers was the triggering factor for these events. Instead, our analysis suggests that permafrost, formed in the region down to 2,525m a.s.l. at 9.3-8 ka and subsequently degrading between 7.8 ka and 6.5 ka, likely played a pivotal role in initiating the first two rock avalanche events. Additionally, permafrost may have been a contributing factor to the third event, which coincided with the warm and wet period of the Holocene Thermal Maximum around 5 ka.

Geomorphological map and morphodynamic analysis of rock glaciers in Val di Spluga (SO) from field and remote sensing surveys

Pietrogrande S.[1*], Azzoni R.S.[1], Tantardini D.[1], Pezzotta A.[1], Tartarotti P.[1] & Zerboni A.[1]

[1]Dipartimento di Scienze della Terra "A. Desio", Università degli Studi di Milano, Via Mangiagalli 34, Milano.

Corresponding author e-mail: sofia.pietrogrande@studenti.unimi.it

Keywords: Geomorphology, Map, Quaternary, Rockglacier, Periglacial.

The high Val di Spluga (Central Alps, Sondrio) exhibits a complex interplay of glacial, periglacial, gravitational, and fluvial processes that have shaped its forms. The realisation of "Foglio 038 - Chiavenna" of the Geological Map of Italy (CARG project) offered the opportunity to conduct a geological and geomorphological survey at altitudes range between 1300 and 3000m asl, and to produce, using the data acquired during two summer campaigns (2022, 2023) and through the analysis of orthophotos (2012, 2018, 2021) provided by the Regione Lombardia bureau, a new geomorphological map and recent deposits at a scale of 1:5.000, and to investigate in detail the dynamism of the periglacial forms. The Val di Spluga is a medium-high mountain valley with valley axis structurally oriented NW-SE. From the area of the lakes towards the ridges, the slope rises gently with a series of rock steps, abraded by the glacier. From the area of the lakes towards the ridges, the slope rises gently with a series of rock steps, abraded by the glacier. The main signs of glaciation in the valley are represented by several moraines, striae on sheepback rocks and erratic boulders, visible up to 2600m asl. Deglaciation following the Last Glacial Maximum (LGM) can be seen with small moraines presents at higher altitudes. During this phase the dominant geomorphological processes passing from glacial to periglacial. Five rock glaciers, ranging from 25.000 to 120.000m^2, are identified, mainly in the southern part. This area is particularly favourable for the maintenance of permafrost, as it is the portion of the valley that is least exposed to the sun throughout the year. Other rock glaciers are identified in the adjacent Val Visogno. Debris at the base of steeper slopes show reworking by nivo-gravitational processes that arrange larger boulders in lobes, named protalus ramparts. The recognized gravity deposits have a genesis mainly from gelifaction and cryoclastism, the resulting material being accumulated by collapse at the foot of slopes, forming scree. This material can then be transported by debris flows and sedimented with juxtaposition and overlapping, forming conoids dominated by debris flows. Landslide deposits are numerous in the valley, with blocks up to decametre in size. Fluvial processes in the valley are limited, with small streams originating from various sources, including the rock glacier identified at Bocchetta di Spluga. These latter flow into the Spluga Lake below, from which the Cavrocco stream originates, cutting through the deposits and bedrock that it crosses. To understand the dynamics of the larger rock glacier, in Val Visogno, photogrammetric drone surveys were carried out, which made it possible to obtain the Digital Terrain Models with a resolution of up to 0.20 m. The available orthophotos and those acquired by drone were compared with each other using the technique of feature tracking of moving points, to trace the movements over time associated with deformation due to creep. The results showed that the central and southern portions of the rock body undergo downstream movements defining an active rock glacier.

Geomorphological evidence of palaeo-coastlines on the continental shelf and implication for the prehistoric communities in the Liguro-Provençal area: an integrated study through multibeam, core data and high-resolution seismic data

Raffa G.[1*], Morelli D.[2], Pepe F.[3], Vacchi M.[1], Starnini E.[1], Zerboni A.[4]& Pappalardo M.[1]

[1] Department of Earth Science, University of Pisa, Italy.
[2] Department of Earth Sciences, Environment and Life (DISTAV), Genoa University, Italy.
[3] Department of Earth and Marine Sciences (DiSTeM), University of Palermo, Italy.
[4] Department of Earth Sciences "A. Desio", University of Milan, Italy.

Corresponding author e-mail: gabriella.raffa@phd.unipi.it

Keywords: sea-level change, Liguro-Provençal Continental Shelf, geomorphological mapping, high-resolution seismic data, digital topo-bathymetric model.

The Liguro-Provençal continental shelf represents a suitable region for investigating the influence of sea-level changes on the palaeolandscape evolution and prehistoric human settlements. Preserved here are traces of morphologies developed in a subaerial environment, which the integrated analysis of topographic and sedimentary features can reconstruct. This study focuses on interpreting the palaeolandscapes recorded on the northwestern Mediterranean Continental Shelf to reconstruct the palaeogeography of the territory where Middle and Upper Palaeolithic cultures thrived. We used multibeam high-resolution bathymetric data with a cell size of 1 x 1 m and a grid of high-resolution seismic profiles (Sparker 1 kJ) calibrated with well-log data. A detailed geomorphological map of the continental shelf in front of the archaeological area of Balzi Rossi was obtained using bathymetry data. This area represents a crossroad of Palaeolithic populations where sea-level indicators from the last 3 to 4 interglacial periods were recorded inland. Morphologies associated with multiple palaeo-coastlines related to sea-level lowstands are also recognised. Notably, a submerged cliff replicates the morphological characteristics similar to the current coastline. This approach aims to verify the interpretation of mapped landforms, chronologically constrain their genesis, and eventually intercept submerged archaeological sites. Data obtained will be compared with relative sea-level curves to determine the position of the paleo coastlines during different stages of the last sea-level rise.

Integrated geomorphological mapping of terrestrial and submarine areas, Gulf of Corinth (Greece)

Rossi S.[1,2*], Tsanakas K.[3], Karymbalis E.[3], Sakellariou D.[4] & Soldati M.[1]

[1]Department of Chemical and Geological Sciences, University of Modena and Reggio Emilia, Modena, Italy.
[2]School for Advanced Studies (IUSS) of Pavia, Pavia, Italy.
[3]Department of Geography, Harokopio University, Athens, Greece.
[4]Hellenic Centre for Marine Research, Avanyssos, Greece.

Corresponding author e-mail: sofia.rossi@unimore.it

Keywords: integrated geomorphological mapping, active tectonics, Gulf of Corinth, Greece.

In this study, an integrated geomorphological map of the Gulf of Corinth, central Greece, is presented. The map covers both terrestrial and submarine environments at a scale of 1:150,000, with the primary goal of delineating the interconnection and continuity of emerged and submerged geomorphological features. The Gulf of Corinth is recognized as the most dynamic neotectonic area in the eastern Mediterranean, exhibiting unique features associated with normal faulting and north-south crustal extension. Notably, active faulting on the southern side resulted in an elevation of more than 950 m during the Pleistocene. To visualize the landforms, advanced GIS techniques were applied on a 25 m DEM used as the topographic basis. The map employs symbolic representation to underscore the persistent nature of submarine landforms and their origins. The terrestrial portion of the Gulf of Corinth displays tectonic uplift in its southern segment, characterized by marine terraces, tidal notches, gorges, and reversed drainage features. In contrast, the northern terrestrial segment showcases a distinctive morphology with drowned valleys and a sinuous coastline. As for submarine landforms, the study reveals a gently sloping northern margin descending to a depth of 400 m, transitioning to a steeper zone between 400 and 800 m. The southern margin features steep slopes (30-40%) incised by numerous small canyons. Both terrestrial and seabed features reflect the region's active tectonics and Quaternary deformation. The overarching aim of this investigation is to bridge the gap between terrestrial and marine geology, providing a comprehensive perspective on the intricate geomorphology of the Gulf of Corinth.

A fluvial record of late Quaternary climate changes and tectonic uplift along the Marche Piedmont Zone of the Apennines

Ruscitto V.[1*], Delchiaro M.[1], Della Seta M.[1], Gribenski N.[2], Iacobucci G.[1], Piacentini D.[1], Zocchi M.[1] & Troiani F.[1]

[1]Department of Earth Sciences, Sapienza University of Rome, P.le Aldo Moro 5, Rome, Italy.
[2]Insitute of Geological Sciences and Oeschger Centre for Climate Change Research, University of Bern, Baltzerstrasse 1, CH-3012, Bern, Switzerland.

Corresponding author e-mail: valeria.ruscitto@uniroma1.it

Keywords: fluvial fill terrace, low-rate tectonics, climate change, semi-automatic terrace extraction.

Fluvial terraces are a pre-eminent continental record of climate changes and tectonics. Although the use of fill terraces for incision rate derivation is complicated due to their cyclical nature relative to strath terraces, they remain a relatively complete record of incision and deposit on, thus allowing one to derive interpretations about both tectonics and climate. The Adriatic piedmont of the Apennines (central Italy) offers a well-preserved staircase of such terraces, caused by the cyclical alternation of fluvial aggradation and incision over the Middle and Late Pleistocene in response to a combination of low-rate tectonic uplift and climate changes. Although the staircase has been already widely described with examples from several valleys of the Adriatic Piedmont, its geochronological constraints are limited and must be enhanced to extract reliable climatic and tectonic signals from terrace deposits—especially for the older terrace levels. This research provides new Optically Stimulated Luminescence (OSL) data on the terrace chronology, in combination with new semi-automatically extracted data on the altimetric and along-valley terrace distributions, as well as the sedimentological characteristics of fill terraces within the Tesino River basin in the Marche piedmont zone of the Apennines. The semi-automatic extraction of the terrace tread allowed a preliminary level classification as a function of the terrace height above the modern channel thalweg. The results demonstrate that, within the slowly uplifting Adriatic piedmont of the Apennines, the main phases of fluvial aggradation occurred during cold and full-glacial conditions followed by river incision and floodplain-channel abandonment during warmer periods. This finding confirms previous results from the last fluvial aggradation-incision cycle (Late Pleistocene). The results also show that the same formation mechanism is valid for the older (Middle Pleistocene) terraces. Indeed, this study provides new geochronological constraints for the regional-scale paradigm of cyclical formation and development of Quaternary fill terrace staircases along this sector of the Apennines. The use of a dated fill terrace staircase allowed estimation of a Middle Pleistocene long-term bedrock incision rate ranging from 0.3 to 0.5 mm yr−1 in agreement with previous studies in the central-northern sector of the Adriatic Apennines. The resulting uplift rate supports the presence of differently uplifted blocks due to the fragmentation of the peri-Adriatic region caused by the activity of left-lateral faults.

Tackling Mediterranean Hurricanes through artificial intelligence in a near-future climate projection

Scardino G.[1,2*], Kushabaha A.[1,3], Sabato G.[1] & Scicchitano G.[1,2]

[1]Department of Earth and Geo-Environmental Sciences, University of Bari Aldo Moro 70125 Bari, Italy.
[2]Interdepartmental Research Center for Coastal Dynamics, University of Bari Aldo Moro, 70125 Bari, Italy.
[3]IUSS – School for Advanced Studies, Pavia, Italy.

Corresponding author e-mail: giovanni.scardino@uniba.it

Keywords: convolutional neural network, cyclone, storm, coastal vulnerability, monitoring.

Mediterranean Hurricanes (known as 'medicanes') are extreme weather systems that cause damage along the Mediterranean coasts. These events are intensifying, and future climate projections show increasingly stronger events than now. Medicane effects are reflected in the high storm surge and coastal flooding that enhance coastal erosion and cause infrastructure damages and casualties. These issues are also intensified by ongoing climate changes, which are determining a global sea-level rise. To address these issues, multiplatform observation systems could be used integrating modern techniques of deep learning. Deep learning models allow us to automatically analyze a large amount of data related to the effects of medicanes and sealevel rise. The main parameters of medicanes are usually correlated to mean sea-level pressure, sea surface temperature, significant wave height, and wind speed. On the other hand, sea-level rise is determining coastal flooding and shoreline retreat, which cause damage to the infrastructure and changes in land use. All these parameters can be assessed from numerical climate models and satellite observations. Furthermore, in-situ data from field surveys could be used to calibrate numerical models and satellite data for target coastal areas. In this work, a Convolutional Neural Network was developed by applying sliding convolutional filters to 1-D inputs in Matlab environment, to assess the vulnerability connected to medicane impact in a framework of future sea-level rise. Here, datasets of meteo-marine parameters from satellite, Copernicus, ERA5 numerical models, morpho-topographical data from LiDAR surveys have been used for the training and validation of the Convolutional Neural Network. The 1-D inputs are represented by vectors where mean sea-level pressure, sea surface temperature, significant wave height, sea-level rise, and wind speed are reported for the medicanes that occurred in the last decades. Regional technical maps and morpho-topographical data have been considered to extract the landforms and areas occupied by buildings and infrastructures, to assess the exposure in the most vulnerable areas. The predictions of Convolutional Neural Network provide an output of the hurricane track and the coastal areas prone to be impacted by storm waves in a given future scenario. For each coastal area, the vulnerability degree is automatically assessed, and the exposure is automatically highlighted through the polygons representing the infrastructures affected by sea-level rise and medicane impact. These findings are particularly useful for multiplatform observation systems to continuously monitor medicane impacts in conjunction with flooding related to future sea level rise.

Estimation of erosion in mountain streams in Sredna Gora Mountain, Bulgaria

Tamburadzhiev I.[1*]

[1]Sofia University „St. Kliment Ohridski", Faculty of Geography and Geology, Department of Climatology, Hydrology and Geomorphology.

Corresponding author e-mail: tamburadzhiev@gea.uni-sofia.bg

Keywords: erosion, river network, morphometric analysis, GIS.

The present study is part of the process of investigating rates and modifications of erosion of selected mountain streams in a part of Sredna Gora Mountain, Bulgaria. The analysis was carried out through the application of GIS-methods to determine the main geometric characteristics of the river network within the scope of the studied area. The short-term erosion rates were evaluated by carrying out a quantitative morphometric analysis within the limits of the selected drainage basins. Various descriptive parameters of the river network were calculated such as area of the basin, perimeter of the basin, number of river channels, total sum of river channel lengths, drainage density, main channel length, shape factor, circularity ratio, uniformity index or compactness coefficient, elongation ratio, sinuosity index, first order channels frequency, bifurcation ratio, direct bifurcation ratio, bifurcation index, hierarchical anomaly number, hierarchical anomaly index, hierarchical anomaly density, as well as the mean turbid transport of streams (Tu). Geomorphological maps of the investigated parts of the selected drainage basins were prepared.

S4.

Spatial methods and analysis in geomorphology

CONVENER & CHAIRPERSON

Lucia Contillo (University of Basilicata)

Methodology for the drafting of a submerged relict deposits plain in the Sicilian Region: work in progress

Gregorio F.[1*], Paltrinieri D.[3], Randazzo G.[1,2] & Lanza S.[1,2]

[1]Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra (MIFT), Università degli Studi di Messina.
[2]GEOlogis s.r.l. Spin Off UNIME.
[3]COREMA Spiagge s.r.l.

Corresponding author e-mail: francesco.gregorio1@studenti.unime.it

Keywords: remote and relict sediments, continental shelf, textural compatibility, VIA-VAS.

From 1960 to 2012, Sicily lost approximately 13 km2 of beach (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2017). According to PRCEC, in Sicily, out of a total coastal development of 1,623 km, the eroding coasts are about 440 km, mostly concentrated in the low-lying beaches, which represent 70% of the coastline. Beaches of incomparable beauty, absolutely iconic and evocative, are being eroded, but it is difficult to intervene in a sustainable way, and so far rigid interventions have shown obvious limits, "blighting" protected beaches and shifting the erosive process underwater.

Any soft defense intervention needs certain sources of supply of borrow material, whether coastal and proximal, useful for local and seasonal interventions (self-transplanting) or marine, submerged, distal, and relict for extensive beach nourishments that restore depth and naturalness to Sicily's eroded beaches. Alternatively, the proposed interventions remain rigid ones with breakwaters and groins, with very limited beach nourishment with often totally unsuitable material.

The Autorità di Bacino della Regione Siciliana, with the support of the University of Messina, is creating a GIS platform populated with administrative, constraint, biological and geological-geomorphological-sedimentological information of the submerged strip of the island, between -30 m (at shallower depths, processes of destabilization of the emerged beach could be triggered) and -200 m (depending on the technical operability of dredging), useful to define the potential areas where it is possible to apply for a sea state concession for the use of submerged, remote and relict sediments (in addition to the two active concessions already issued by the Sicilian region) to be used primarily for soft defense interventions (artificial nourishment). All this in consideration that the needs for possible beach nourishment to be carried out in Sicily can be estimated at about 30 million cubic meters, to which must be added the material for the physiological cyclical recharge of beach nourishment operations.

The project also includes the definition of those stretches of sea where, depending on the sedimentological and geomorphological characteristics, beach restoration interventions can be carried out, through cyclical/seasonal auto-transplantation of proximal sediments, as required by Ministerial Decree 173/2016. This information will flow into a WEBGis open to the public that will support professionals, businesses and public administrations for better planning and implementation of the different types of interventions, optimizing, in addition, the dissemination of data useful for environmental impact studies that are currently considered an insurmountable obstacle for proponents.

Towards the automatic identification of agricultural terraces in the Eastern Mediterranean using open access Earth observation data

Kedich A.[1,2*], Vanmaercke M.[1], Vandam R.[2], Vervust S.[2], Verstraeten G.[1], Devos Y.[2] & Cerón-González A.[1,2]

[1]Division of Geography and Tourism, Department of Earth and Environmental Sciences, KU Leuven, Heverlee, Belgium.
[2]Archaeology, Environmental Changes & Geo-Chemistry research group (AMGC), Vrije Universiteit Brussel, Brussels, Belgium.

Corresponding author e-mail: andrei.kedich@kuleuven.be

Keywords: agricultural terraces, Mediterranean, soil erosion, Object-based image analysis (OBIA), machine learning, deep learning.

Agricultural terraces are one of the most significant anthropogenic land modifications in the Mediterranean. They are constructed to decrease local slope gradients and promote cultivation in lands that are otherwise unfavorable for farming. When terraces are built, they can reduce soil erosion, locally increase soil thickness, and enhance water infiltration. However, if not maintained or abandoned, there is an increased risk of erosion and/or slope failures. Additionally, the increase in erosion can be associated with the lowering or even full removal of natural soil stoniness, which is necessary for constructing the stone walls and facilitating cultivation. This can further increase the soil susceptibility to erosion. Incorporating these complex effects of terraces in hydrological, geomorphic, and agronomic models often remains challenging, especially because accurate information on their locations and characteristics is lacking. The goal of this study is therefore to develop techniques that allow for the (semi-)automatic detection of terraces, based on freely available data products. We aim to create a scalable tool for terrace detection in large regions (> 1000 km²). For this, we first selected a test site: the Sagalassos territory in Türkiye (~1200 km²). This area is located around the ancient city of Sagalassos and has significant archaeological importance, with human activity peaks during the Hellenistic and Roman times. The territory is characterized by smaller settlements, roads, and various agricultural parcels. This area has a history of human settlements and agricultural activity dating back to 8000 BP and has a wide variety of terraced areas. These terraces vary from old abandoned ones with partially collapsed stone walls to newly constructed ones. To identify terrace locations within the study territory, we utilize current-day high-resolution optical imagery from Google Earth and medium-resolution ASTER DEM, which are openly available. We employ object-based image analysis (OBIA) to perform a simple binary classification between terraced and non-terraced areas. We test and compare various metrics such as texture measures and some custom approaches that can be used to differentiate terraced from non-terraced areas. These metrics further incorporated into the different machine learning classification approaches such as Random Forest and Support Vector Machine (SVM). Additionally, we plan to evaluate the performance of deep learning techniques, specifically using the U-Net and DeepLabV3+ architectures, which require more computational power, but are known to be the most accurate. Overall, our research aims are to find an optimal balance between classification accuracy and computational capabilities, enabling the applicability of the approach to other areas and ensuring scalability.

Mapping the impacts of Mediterranean Hurricanes by integrating relational geodatabase in Web-GIS platform

Kushababa A.[1,2*], Scardino G.[2,3], Sabato G.[2] & Scicchitano G.[2,3]

[1]School for Advanced studies-IUSS, Pavia, Italy.
[2]Department of Earth and Geoenvironmental Sciences, University of Bari, Italy.
[3]Interdepartmental Research Center for Coastal Dynamics, University of Bari Aldo Moro, 70125 Bari, Italy.

Corresponding author e-mail: alok.kushababa@iusspavia.it

Keywords: Mediterranean hurricanes, climate datasets, remote sensing, geodatabase, Web-GIS.

The coastal areas of the Mediterranean Sea experiencing effects due to various cyclogenesis phenomena. This research focuses on studying the effects of cyclones in the Mediterranean Sea, specifically Mediterranean Hurricanes, which cause significant damage to coastal areas. Advanced remote sensing and Geographic Information System (GIS) techniques were employed to analyse climatic data and observe geomorphological evidence, such as flooding, coastal erosion, landslides, and debris flow. By integrating climate features and geomorphological evidence, this study establishes a connection between the occurrence of Mediterranean Hurricanes and their impacts. The investigation was focused on the south-eastern coasts of Sicily, where Mediterranean Hurricanes have caused extensive damages like flooding, erosion, and storm surges. To assess coastal flooding and erosion, pre- and post-storm morpho-topographical surveys were performed using aerial photogrammetry and Terrestrial Laser Scanner surveys. The data collected were stored in a geodatabase, enabling the visualization of climate features and geomorphological evidence. Moreover, an open-source Web-GIS platform integrated with the geodatabase was developed to facilitate the sharing of geographic information among stakeholders and researchers, fostering collaboration and informed decision-making. This study enhances our understanding of Mediterranean cyclones and aids in the preparation of effective coastal management strategies to mitigate the challenges posed by Mediterranean Hurricanes.

Remote sensing-based suspended sediment discharge modelling: A support for investigating climate change impacts on sediment transport dynamics

Mohsen A.[1,2*], Kovács F.[1] & Kiss T.[1]

[1]Department of Geoinformatics, Physical and Environmental Geography, University of Szeged, Egyetem u. 2–6, 6722 Szeged, Hungary.
[2]Department of Irrigation and Hydraulics Engineering, Tanta University, 31512 Tanta, Egypt.

Corresponding author e-mail: ahmed_mohsen250@f-eng.tanta.edu.eg

Keywords: Sentinel-2, rating curve, hydraulic geometry, tributary, machine learning.

The alternations in precipitation patterns, temperature variations, and extreme weather events induced by climate change significantly influence erosion, sedimentation patterns, and, consequently, sediment transport in rivers. Remote sensing techniques with their large-scale coverage, frequent monitoring and extended historical time series provide a valuable tool for investigating the spatiotemporal dynamics of suspended sediment transport (Qs) in response to climate change variables. However, previous research focused on developing remote sensing-based models solely for suspended sediment concentration (SSC), relying on measured water discharge (Q) for Qs estimation. Therefore, this study aimed to model both components of Qs integrating intensive in-situ SSC and Q data with Sentienl-2 images and machine learning algorithms. The in-situ data was measured monthly at three gauging sites in the Lower Tisza (Algyő and Szeged) and Maros (Makó) Rivers between 2015 and 2021, along with concurrent 29 Sentinel-2 images. The hydraulic geometry theory, especially the water width-Q relationship served as the basis for Q modelling, as Sentinel-2-based width data estimated at the three gauging sites were fitted with measured Q by the at-a-station hydraulic geometry (AHG) power law, at-many-station hydraulic geometry (AMHG) and a novel AHG machine learning methods. Simultaneously, SSC was modelling by fitting Sentinel-2 reflectance data with measured SSC at cross-sections by random forest, support vector machine and artificial neural network algorithms. The findings revealed the elevated potential of satellite sensors in estimating Q, with AHG machine learning models exhibiting superiority (R2=0.7; RMSE=140 m3/s). However, this approach is very sensitive to width data estimates, cross-section shape, and may provide inaccurate Q estimations above the bankfull level due to losing hydraulic geometry characteristics. Among the three tested algorithms for SSC modelling, random forest-based models demonstrated superior accuracy (Tisza: R2=0.8; Maros: R2=0.85). Nevertheless, caution is warranted in interpreting SSC estimates near riverbanks and shallow sections, where pixel reflectance is mixed between water and land. Integrating the best-derived developed Q and SSC models offers a promising approach for estimating Qs and exploring the intricate spatiotemporal dynamics influenced by climate changes.

Integration of Remote and Proximal Sensing techniques in slow-moving landslide investigation in the Scoltenna basin, Northern Apennines (Italy)

Parenti C.[1,2*], Grassi F.[2,3], Rossi P.[2,3], Mancini F.[2,3], Pattuzzi E.[4] & Soldati M.[1,2]

[1]Department of Chemical and Geological Sciences, University of Modena and Reggio Emilia, Via Campi 103, 41125 Modena, Italy.
[2]CRICT—Inter-Departmental Research and Innovation Centre on Constructions and Environmental Services, University of Modena and Reggio Emilia, Via Vivarelli 10, 41125 Modena, Italy.
[3]Department of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, Via Vivarelli 10, 41125 Modena, Italy.
[4]Regional agency for territorial safety and civil protection of Emilia-Romagna, Viale Silvani 6, 40122 Bologna, Italy.

Corresponding author e-mail: carlotta.parenti@unimore.it

Keywords: slope instability, integrated monitoring, remote sensing, Northern Apennines (Italy).

In mountain environments, landslide activity can be assessed through a variety of remote and proximal sensing techniques at different scales of investigation and the combination between them. The complementarity of different methods and techniques and the synergistic use of the data collected can be crucial for the recognition and monitoring of hillslope processes. The aim of this study is the investigation of slow-moving landslides in the Scoltenna basin (Northern Apennines, Italy) through an integrated methodological approach that combines remote and proximal sensing techniques. The study area is widely affected by active and dormant landslides which are the dominant geomorphological process in the valley. This research work shows the results of the activities conducted on three sites affected by earth flows / earth slides (La Confetta, Ponte Olina and Sasso Cervaro landslides) by integrating geomorphological field surveys and different remote sensing techniques, in order to detect their state of activity and monitor their evolution through time. In particular, satellite interferometry, global navigation satellite systems surveys (GNSS), aerial photogrammetry based on uncrewed vehicles, and terrestrial laser scanning were used. Historical aerial photos from the Regione Emilia-Romagna Web Map Service and high-resolution satellite images from Google Earth were also analysed. All data collected were organized in a multitemporal perspective, referred to the same georeferenced system and implemented in a Geographic Information System (GIS) environment. The study, besides providing clues on the state of activity and evolution of exemplary cases of slow-moving landslides of the Northern Apennines, shows how the use of integrated different remote and proximal sensing techniques can be beneficial in supporting investigation of slope dynamics in clayey terrains. The integration of data collected from different methodologies (InSAR, GNSS, UAV photogrammetry and TLS) overcame the limitations of each technique and allowed the validation of the results obtained. The application of this integrated methodological approach detected centimetric displacements at the three investigated sites and highlighted that the most significant displacements through time appear at the foot of the landslides where interaction with fluvial activity takes place.

Developing an Automated Tide and Surge Measurement System in Coastal Regions Using Deep Learning Techniques

Sabato G.[1*], Scardino G.[1], Kushabaha A.[1,4], Casagrande G.[2], Chirivì M.[3], Fontolan G.[2], Fracaros S.[2], Luparelli A.[3], Spadotto S.[2] & Scicchitano G.[1]

[1]Department of Earth and Geoenvironmental Sciences, University of Bari, Italy.
[2]Department of Mathematics, Informatics and Geosciences, University of Trieste, Italy.
[3]CETMA (Centro di Ricerca Europeo di Tecnologie Design e Materiali), Brindisi, Italy.
[4]IUSS – School for Advanced Studies, Pavia, Italy.

Corresponding author e-mail: gaetano.sabato@uniba.it

Keywords: deep learning, tide, storm surge, coastal monitoring.

The most recent advances in machine learning and deep learning methodologies are generating great interest in a variety of research fields, including environmental studies. By facilitating automated and remote collection of data, these new tools have changed approaches to measuring maritime features. This research focuses on the development of a deep learning model to automatically measure tide and surge, with the goal of achieving precise results through the analysis of security camera data. The deep learning model was used to predict tide and storm surge from surveillance cameras strategically placed in two different coastal locations namely Santa Lucia in southeastern Sicily and Lignano Sabbiadoro in Friuli Venezia Giulia, Italy, adopting the Inception v3 architecture. The deep learning model uses categorization methods to assign a water level value to a given frame. This approach is especially useful in situations where typical tidal sensors are inaccessible or too far away from measurement stations, such as during extreme events requiring precise surge observations. The dataset employed to train and validate the deep learning model encompasses the full range of tide values observed in the study areas. The accuracy of the system was evaluated by comparing the predictions generated by the deep learning model with the corresponding tide gauge values. The experiments conducted clearly show that the model is quite effective in measuring tide and surge remotely, achieving an accuracy of over 90% and keeping the loss value below 1 for the deep learning model. These results highlight the model's ability to address the absence of data collection in difficult coastal environments, providing valuable information for coastal management and hazard assessment. This research significantly contributes to the expanding realm of remote sensing and machine learning applications in environmental monitoring, enhancing understanding and decision-making in coastal regions.

Analyzing anthropogenic impact on river morphodynamics in the Upper Orcia Valley (central Italy) through multitemporal NDVI assessment

Sannino A.[1*], Vergari F.[1], Iacobucci G.[1] & Del Monte M.[1]

[1]Department of Earth Sciences, Sapienza University of Rome, Rome, Italy.

Corresponding author e-mail: annalisa.sannino@uniroma1.it

Keywords: river morphodynamics, badlands, NDVI, LULC, erosion.

Mediterranean environments are significantly shaped by human activities, and the morphology of rivers often reflects centuries of human intervention for land development. Previous studies, spanning decades, have highlighted the drastic river adjustments in the Italian landscape. These adjustments often reflect the man-induced land use changes within the drainage basin. The analysis of the rivers in Tuscany site (central Italy), has revealed profound changes, especially in terms of channel bed narrowing and incision. This work presents the fluvial system scale analysis of the anthropogenic impact in the Upper Orcia Valley (southern Tuscany), that undergone a huge land reclamation, as evidenced by the archives of the Land Reclamation Authority, established in 1929. Accelerated erosion landforms, such as *calanchi* and *biancane* badlands, have been extensively reduced by this intervention. Consequently, a multitemporal analysis indicates a decreasing trend in erosion rates over the recent decades, accompanied by an increase in agricultural and forested areas and a narrowing of river channels. To comprehend the role of land cover and land use changes in river dynamics, the results of a multitemporal geomorphological survey and an analysis of land use changes were compared with spatio-temporal computation and analysis of the NDVI (Normalized Difference Vegetation Index), commonly used in ecology to gauge the impact of green biomass on soil erosion. NDVI was computed using Landsat and Sentinel multispectral imagery (Landsat 1-2-4-5-8 and Sentinel-2), selecting images acquired every 5 years in May, corresponding to the Start of Seasons (SOS) month, within the 1975-2021 timeframe. The results revealed a general decrease in bare lands and a significant increase in dense vegetation cover. The overlap this data with multitemporal geomorphological mapping demonstrated a recolonization by forests along main riverbeds and in badland areas, indicating a reduction in sediment supply from hillslopes, possibly causing the observed channel narrowing and incision trends along main rivers. These findings can be attributed to increased land use for agriculture, artificial reforestation, and the gradual abandonment of rural areas, leading to the recent reconquest of broad-leaved forests.

Validation of shoreline detection by applying semi-automatic algorithms based on multispectral satellite sensors on the beach with *Posidonia oceanica* banquettes; case study of Arborea beach (Sardinia, Italy)

Terracciano S.[1*], Montes Pèrez J.[2], Brunetta R.[1], Cabrita P.[1], Duo E.[1], Ciavola P.[1,4] & Armaroli C.[3]

[1]University of Ferrara, Department of Physics and Earth Sciences, Italy.
[2]Department of Earth Sciences, University of Cadiz, Spain.
[3]Department of Biological, Geological and Environmental Sciences, University of Bologna Alma Mater Studiorum, Italy.
[4]CNR-IAS Oristano, Istituto per lo studio degli Impatti Antropici e Sostenibilità in ambiente marino, Italy.

Corresponding author e-mail: trrsrn@unife.it

Keywords: remote sensing, CoastSat, SAET, Posidonia oceanica.

Recent advancements in satellite remote sensing, including a growing sensors' resolution and enhanced data processing, are improving the capabilities of monitoring coastal environments. Of particular interest in this area of research are algorithms for the (semi)automatic detection of shorelines on high-resolution images. However, these algorithms are often tested under ideal conditions on sandy beaches and limited validation is available for shorelines with deposits of different materials (e.g., vegetation debris) on the sand's surface, which can impact the algorithm's performance. The accumulation of diverse biomass, combined with sand, gives rise to formations known as 'banquettes'. Depending on the geomorphological setting of the coast, these formations can reach heights of up to 2 meters and stretch for hundreds of meters. The presence of these banquettes in swash/intertidal zones poses a challenge, increasing inaccuracies in identifying the sand-water interface.

The aim of the study is to validate the Satellite-Derived Shoreline (SDS) obtained from the algorithms SAET (https://doi.org/10.3390/rs15123198) and CoastSat (https://doi.org/10.1016/j.envsoft.2019.104528) from Sentinel-2 (S2), Landsat-8 (L8) and Landsat-9 (L9) multispectral images. The validation and accuracy analysis were conducted using RTK-GNSS surveys carried out during fieldwork campaigns as part of the OVERSEE project. The selected study area is Arborea beach, situated in the Gulf of Oristano in the western coast of Sardinia region. The beach is of particular interest due to its gently sloping seafloor, which contributes to the accumulation of banks of *Posidonia oceanica*. The use of S2, L8 and L9 allows for a comparison with different spatial resolutions (10 m for the panchromatic band of S2 and 15 m for the panchromatic bands of L8 and L9). Additionally, this approach is employed to investigate the efficiency of algorithms that operate using all available and fit-for-purpose imagery (e.g. low or absence of cloud cover) over the time frame of the analysis.

Upon conducting error analysis, it was revealed that the accuracy obtained aligns closely with the spatial resolution of the satellite. Indeed, we observed that CoastSat yields larger errors compared to SAET, with an average error of approximately 20 meters compared to the fieldwork surveys. This error derives from the misclassification or failure to recognise various land cover categories, particularly the sand class, which is often confused with artificial structures or missed due to its dark hue. This approach allows us to assess the accuracy levels of the analysis and to highlight the various constraints inherent to each methodology. Finally, the results obtained from this study demonstrate the advantages of adopting different algorithms, each using distinct image processing modes and spectral indices.

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Detecting landslide system dynamics with PS-InSAR post-processing: the case study of the DeBeque Canyon Landslide (Colorado, USA)

Zocchi M.[1*], Delchiaro M.[1], Troiani F.[1], Mazzanti P.[1,2] & Scarascia Mugnozza G.[1,2]

[1]Department of Earth Sciences, Sapienza University of Rome, P.le Aldo Moro 5, 00185 Rome, Italy.
[2]Department of Earth Sciences and Research Centre for the Geological Risks (CERI), Sapienza University of Rome, 00185 Rome, Italy.

Corresponding author e-mail: marta.zocchi@uniroma1.it

Keywords: remote sensing, CoastSat, SAET, Posidonia Oceanica.

Deciphering the heterogeneous displacement pattern for landslide systems is particularly challenging given the intricate interplay of different kinematics and the nesting of multiple sectors. In these cases, reactivation, and failures of one or multiple sectors of the landslide constitute a crucial element in the strategic planning of mitigation measures, which must consider a heterogeneous hazard pattern, both in the spatial and temporal domain. With its three interrelated sectors evolving as rockfalls, translational and rotational rockslides, the DeBeque Canyon Landslide (DCL), interfering with one of the strategic assets of the Colorado State (USA), poses a significant concern for transportation agencies as it impacts a crucial asset in the state of Colorado, USA. To entangle the high degree of internal fragmentation, we employed a detailed post-processing of a Persistent Scatterers Interferometry (PSI) analysis. The multi-geometry dataset was combined to derive a bi-dimensional vector representing the displacement rate and gradient of the investigated phenomenon. From a spatial perspective, we distinguished a gradual transition from translational to rotational dynamics within the DCL system through the statistical distribution analysis of the bi-dimensional vector in parallel with its projection on different topographic profiles intersecting each sector. Moreover, a Bayesian temporal analysis of the vector's time series leads to the identification of acceleration stages within the displacement trend. The Bayesian model applied to time series derived the probability of occurrence of abrupt changes based on the analysis of hundreds of displacement measurements, thus strengthening the correlation analysis between accelerations in disruption rates and external forcings (i.e., precipitation and temperature). The precise examination of the intricate DCL system was pivotal in comprehending its dynamics and formulating a conceptual model of the superimposed failure mechanisms and preparatory and triggering factors. The outcomes of our research hold significance for future studies aiming at evaluating geo-hazards with complex spatial-temporal behaviours threatening infrastructures and standing as a beneficial practice to consider within assets management frameworks. Additionally, within the context of climate change, the alterations in rainfall distribution and intensity, coupled with rising temperatures, influence the timing and triggering of various processes. This can consequently alter the response of landslide systems, necessitating continuous, cost-effective monitoring. Our approach not only offers a replicable method for characterizing and monitoring heterogeneous displacement patterns but also serves as an efficient and economical solution for transportation agencies in mitigating risks associated with such changes.

S5.

Geomorphological hazard

CONVENER & CHAIRPERSON

Carlotta Parenti (University of Modena and Reggio Emilia)

Codifying a database framework of climate change geomorphological markers: a first effort for a case-study from southern Italy

Contillo L.[1*], Corrado G.[1] & Schiattarella M.[1]

[1]Dipartimento delle Culture Europee e del Mediterraneo, Università degli Studi della Basilicata, Matera.

Corresponding author e-mail: lucia.contillo@unibas.it

Keywords: climate change, geomorphological indicators, inner areas, southern Italy.

In the last decades, global change effects are affecting large parts of inner areas of southern Italy. For example, climate seems to be a major driving factor, as well as human factors, in the recent fluvial dynamic evolution in Italy (Scorpio et al., 2015; de Musso et al., 2020; Mandarino, 2022). The intensity of extreme rainfall events represents trigger and driving factor for fluvial erosion and mass-wasting processes, in terms of efficiency and rates, which affect the slope stability also in Mediterranean badland areas. During times of global change, analysing different phases of gully erosion processes, and collecting information on sediment source areas and mobilized sediment volume become a fundamental step for a better understanding of geomorphic changes caused by extreme events (Coratza & Parenti, 2021). Similarly, river systems provide a potential record of landscape evolution in a particular climatic framework. Measuring certain geomorphic parameters means monitoring and understanding river evolution over time (Zingaro et al., 2022). Analysing some categories of markers in key areas where climate changes may cause environmental hazard seems a best practice for the territory safeguard. Sedimentary and geomorphological indicators of climate change in rural areas of Basilicata (southern Italy), referred to both streams and slopes, will be analysed: channel bed modifications; accelerated erosion landforms; erosion and sedimentation rates; sediment connectivity evolution; rainfall/temperature multi-temporal values; dry/wet periods distribution; flood events frequency; drainage density (Dd) variations. Such parameters can be measured by applying different techniques (direct or indirect – field surveys, Internet-of-Things, remote sensing techniques, historical data), and using appropriate spatial scales (e.g., from channel scale to badlands) and temporal scales (long-, medium- and short-term monitoring). The aim is to provide an operational protocol for the climate change impact assessment approach to be repeated in the future over wider areas.

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Reconstruction of the fluvial landscape of Erbil (Kurdistan Region of Iraq): the anthropogenic impact on landforms and present-day geomorphological hazard

Forti L.[1*], Azzoni R.S.[1], Pelfini M.[1] & Zerboni A.[1]

[1]Dipartimento di Scienze delle Terra "A. Desio", Università degli Studi di Milano, I-20133 Milano, Italy.

Corresponding author e-mail: luca.forti@unifi.it

Keywords: Urban geomorphology; Anthropocene; Fluvial geomorphology; Erbil; Kurdistan Region of Iraq.

The city of Erbil (Kurdistan Region of Iraq) was established along a fertile alluvial plain in northern Mesopotamia during the Chalcolithic period and grew around the pristine citadel, which was likely built on top of fluvial features. Prior to the mid-20th century, Erbil was centred around the citadel and relied on traditional systems for water management such as artificial basins and qanats. The city underwent intense urban expansion since the 1950s and changed its shape due to the construction of roads and residential and industrial areas, which led to the obliteration of the pristine fluvial network. The analysis of historical and current satellite images highlights the profound modification of the landscape triggered by human actions and a progressive shift of local land use from agricultural to urban. This, coupled with human agency on the natural hydrography led to the increase susceptibility of the city to geomorphological hazard (especially floods). The geomorphological reconstruction of the urban landscape of Erbil aimed at explaining how human groups settled the region since the prehistory and contributed modifying natural surface processes. Our reconstruction on landforms evolution based on satellite and historical aerial images and field control allowing the reconstruction of changes in land use over time. Our investigation suggests that during the Anthropocene the dynamic of urbanization reach a tipping point, when excessive urban growth suffers the effect of geomorphological hazard. For that reason, urbanization in the Anthropocene must consider the existence of natural geomorphological processes. This is preliminary contribution to the "GEOTRes – Geoheritage threating and resilience: mapping the impact of geomorphic and human processes in sensitive morphoclimatic environments" projects supported by MUR, PRIN2022 (PI. R.S. Azzoni)

Thermal photogrammetry on a permafrost rock wall for the active layer monitoring

Ponti S.[1*], Girola I.[1] & Guglielmin M.[1]

[1]University of Insubria, via J.H. Dunant, 3, Varese – 21100 (Italy).

Corresponding author e-mail: stefano.ponti@uninsubria.it

Keywords: permafrost, active layer, Unmanned Aerial Vehicle, thermal photogrammetry.

Permafrost and active layer models often cannot explain the high spatial variability, especially in heterogeneous environments like the mountainous regions due to their scarce resolution, paucity of climatic data and topographic details. In this study, we want to introduce a new application of the unmanned aerial vehicle (UAV) in thermal photogrammetry to model the active layer thickness (ALT) of an alpine rock wall through the computation of the thermal inertia and compare the results with a widespread ALT model. On the Gran Zebrù South rock wall, 8 thermal UAV surveys has been conducted in 4 different summer days during 2021-2022 in order to have two 3D thermal models per day at different solar radiation inputs. By analyzing topographic data, visible imagery and the thermal models, the apparent thermal inertias (ATIs) have been converted into heat transfer coefficients (HTCs) and then into ALT of 2021 and 2022. These maps have been validated through the placement of thermistors at different elevations and with variable depths (2, 15 and 40 cm from the rock surface). The resulting ALT has been compared with the Stefan's solution and the alpine permafrost index map (APIM), which showed large underestimations and a non-correspondence with permafrost occurrence. The average ALT increase of 29.3 cm from 2021 to 2022 has been discussed regarding permafrost formation/degradation future trend under the climatic change and potential risks of alpine areas.

Temporal variability of sinkhole hazard assessed by means of multi-temporal mapping in the western shore of the Dead Sea

Sevil-Aguareles J.[1*] & Gutiérrez F.[1]

[1]Universidad de Zaragoza; Departamento de Ciencias de la Tierra; c. Pedro Cerbuna 12; 50009; Zaragoza; España.

Corresponding author e-mail: jorge.sevil.aguareles@gmail.com

Keywords: multi-temporal mapping, frequency-size relationships, sinkhole hazard, spatial redundancy.

Quantitative sinkhole hazard assessments are scarce despite the increasing economic and societal sinkhole-related damage worldwide. This can be attributed to the difficulty of compiling complete sinkhole inventories and the common lack of chronological data. These limitations may lead to minimum hazard estimates and the presumption that the probability of occurrence of sinkholes remains steady over time, which may result in costly hazard over- or under-estimations. The extraordinarily high frequency of sinkhole occurrence in the studied sector of the eogenetic salt karst of the Dead Sea has allowed us to explore for the first time the temporal variability of sinkhole hazard parameters. We produced six multi-temporal sinkhole inventories with morphometric data within a 2 km^2 sector of the western shore of the Dead Sea. The cartographic inventories were created using remote-sensed imagery and GIS software, encompassing the 2005-2021 period. The frequency-size relationships derived from the 667 new sinkholes allowed us to identify significant temporal changes in the hazard parameters, illustrating that sinkhole hazard can be a non-steady variable. Furthermore, our analysis revealed that neglecting spatial redundancy (i.e., sinkholes nested within or intersecting pre-existent ones) can result in a considerable hazard overestimation in areas with densely distributed and clustered sinkholes. In summary, our investigation illustrates the usefulness of multi-temporal cartographic sinkhole inventories for analyzing the spatial-temporal patterns of sinkhole evolution and hazard variability.

Coastal vulnerability assessment in north-western Malta: A Mediterranean climate-change hotspot

Sarkar N.[1,2*], Rizzo A.[3,4], Vandelli V.[1*] & Soldati M.[1]

[1]Department of Chemical and Geological Sciences, University of Modena and Reggio Emilia, Modena, Italy.
[2] School for Advanced Studies (IUSS) of Pavia, Pavia, Italy.
[3] Department of Earth and Geo-Environmental Sciences, University of Bari Aldo Moro, Bari, Italy.
[4] Interdepartmental Research Center for Coastal Dynamics, University of Bari Aldo Moro, Bari, Italy.

Corresponding author e-mail: vittoria.vandelli@unimore.it

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In the context of climate change, the Mediterranean regions are expected to face the highest number of adverse impacts, with discernible negative consequences also on coastal areas. The Maltese Islands, being in the central Mediterranean Sea, can be considered a prominent climate change hotspot. The Islands are prone to be affected by both climate- and marine- related processes including coastal erosion, flooding, rock falls and, on a long-term, sea-level rise. These hazardous processes make coastal vulnerability a major concern, with the potential to cause significant economic losses, possible damage to the cultural heritage and detriment of natural habitats and biodiversity. Assessing coastal vulnerability is a complex task due to many factors such as the limited data availability, the varied aspects of vulnerability (involving a combination of physical, ecological, social and economic factors), and the dynamic nature of coastal systems. Considering these complexities, it is of great importance to develop methodologies for coastal vulnerability assessment that can rely on accessible data and that can be tailored to local dynamic settings within the context of climate change. This is crucial for the effective management of coastal areas and the implementation of adaptive strategies. In response to these challenges, this work proposes a comprehensive methodology for the assessment of coastal vulnerability by applying an index-based approach integrated and validated through geomorphological field surveys. The methodology was applied along the hazard-prone north-western coast of Malta, a region crucial for tourism, making the assessment of coastal vulnerability a primary issue. The overall vulnerability was estimated by taking into consideration three physical indicators, related to land use, anthropic assets, and natural assets within well-defined areas prone to erosion, flooding, or rock falls. Moreover, field surveys were performed to adjust and validate the application of the methodology. The results indicate that the most critical spots of the north-western coast of Malta are bay areas, where the impacts of coastal hazards are expected to be higher. This high vulnerability is mainly due to the presence of significant economic activities and tourist attractions, including some of the most popular Malta's sandy beaches. These areas hold both economic significance and ecological and social importance. The obtained results not only improve the understanding of Maltese coastal vulnerability but also lays the groundwork for efficient coastal management and adaptation strategies. In fact, the application of this method intends to contribute to an overall risk characterization offering a useful tool for the identification of the most vulnerable zones requiring priority actions and protection measures. Furthermore, the adaptability and accessibility of the methodology make it transferable to other coastal regions facing similar challenges.

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