5th Joint International Symposium on Deformation Monitoring (JISDM), 20-22 June 2022, Valencia, Spain
DOI: http://doi.org/10.4995/JISDM2022.2022.13755

4D point cloud analysis of the September 2020 Medicane impact on Myrtos beach in Cephalonia, Greece

Emmanuel Vassilakis, Aliki Konsolaki, Stelios Petrakis, Evangelia Kotsi, Christos Fillis, Stelios Lozios, Efthymios Lekkas

National and Kapodistrian University of Athens, Zographou, Greece, (evasilak@geol.uoa.gr; alikikons@geol.uoa.gr; spetrakis@geol.uoa.gr; ekotsi@geol.uoa.gr; chfilis@geol.uoa.gr; slozios@geol.uoa.gr; elekkas@geol.uoa.gr)

Key words: *mudflow*; *photogrammetry*; *landslide*; *coastal management*; *Unmanned Aerial Systems*

ABSTRACT

The coastal area of Myrtos beach, is a very popular Natura protected area at the Northern part of Cephalonia Island, in W. Greece, which suffered severe damages during the Medicane named after “Ianos”, that affected the Greek territory in September 2020. Most of the steep slope area, which hosts the road that leads to the beach area itself were extensively covered by debris due to mudflows, interrupting aggressively the road connection with the inland network. The use of Unmanned Aerial Systems proved to be an ideal way of mapping quite small areas, with limited access to road networks. The generation of ultra-high resolution spatial products seems to be optimal for mapping and quantifying mass movements that cover areas ranging from less than one square kilometer up to few square kilometers. The aim of such a multi-temporal study, which is described herein, contains aerial image data collection and analysis, before and after the catastrophic event. It is leading to the quantification of the surface topographic changes, by generating a time series of point clouds, after creating several terrain models along with ortho-photo-mosaics, based on Structure-from-Motion photogrammetric techniques. The digital comparison of the co-registered photogrammetric products showed that significant surface alterations have taken place due to the 2020 Medicane. The diachronic point clouds led to the detection and quantification of elevation changes, mainly at the central part of the area of interest, whereas the elevation values of the point clouds were found rather altered, before and after “Ianos”, either positively (deposition) or negatively (erosion), delineating the areas that suffered surface changes.

I. INTRODUCTION

During the recent years, the demands on very high-resolution topography data are constantly increasing, leading to the generation of ultra-high density point clouds, which are used for the construction of Digital Surface Models (DSMs) and Ortho-photo-mosaics. Structure-from-motion (SfM) photogrammetry and multi-view stereo (MVS) have given the scientific community the opportunity to generate 3D topographic and morphological data derived from data based on the use of Unmanned Aerial Systems (UAS), with pixel sizes that reach even few millimeters. Moreover, the opportunity to use time as the fourth dimension, provide the capability to detect topographic changes at a very high resolution and accuracy.

One of the main issues regarding the topographic change detection, is the requisiteness of very accurate georeferencing. There are several methods to achieve accurate positioning, such as Ground Control Point (GCP) based georeferencing method (James *et al.*, 2017), direct georeferencing method (Zhang *et al.*, 2019) and a post-processing georeferencing method with the use of ‘pseudo-GCPs’ (Peppa *et al.,* 2018). The latter, seems to be adequate for the work that is described in this manuscript, since the meantime between the two periods of data acquisition (July 2020 – October 2020, before and after the Ianos Medicane) is too short and the uncovered terrain characteristics of the wider area remain relatively stable and clear.

The area of interest was photographed twice by a large number of overlapping aerial images. As generally accepted, a sequence of a relatively low-cost UAS time series dataset can provide useful support for the delineation of the earth’s surface structures and specifically for the study of gravitational processes evolution (Niethammer *et al.*, 2012; Liu *et al.*, 2015). Furthermore, landslide monitoring within the framework of multi-temporal UAS data acquisition is a method that could produce accurate results after careful data collection and photogrammetric processing (Turner *et al.*, 2015; Rossi *et al.*, 2018; Seier *et al.*, 2018).

The purpose of multi-temporal UAS data collection and analysis is to create a series of DSMs along with ortho-photo-mosaics (Westoby *et al.,* 2012; Granshaw, 2018; Mauri *et al.,* 2021), to quantify the surface topographic changes.

High-resolution images acquired by a small but accurately located UAS may support the definition of not only the identification of the actual margins of a studied landslide phenomenon but also the identification and mapping of the main geomorphological features (Fiorucci *et al.*, 2018; Karantanellis *et al.*, 2019), either based on the classic methodologies or by using more sophisticated and automated state-of-the-art techniques (Karantanellis *et al.*, 2020).

II. Site and Medicane description

The area of Myrtos beach, is a popular 800 m long coastal area, sited in the northern part of Cephalonia Island (Figure 1) and protected by Natura 2000 network. The beach is rather small (average width of 50 m) and is located under a rather steep slope, consisting of loose highly tectonised rocks, which in turn have produced a thick surface layer consisted of large amounts of cobbles and boulders.

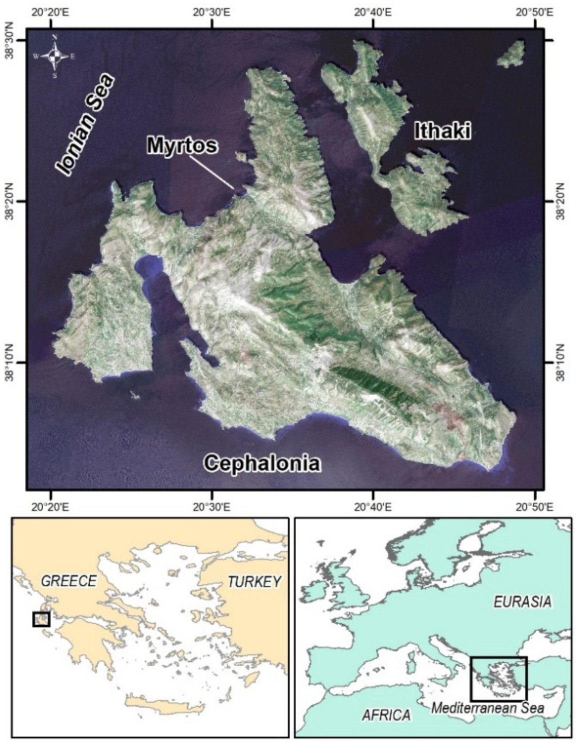

Figure 1. The Natura 2000 protected Myrtos beach is located at the NW coastline of Cephalonia Island. See at the bottom index map its location in the context of Greece and Europe, respectively.

In the past few years, the area has suffered extended landslides, rockfalls and mudflows (Mavroulis *et al.,* 2022), and therefore informative «danger» plates have been placed along the beach for the protection of the visitors.

In September 2020, the Medicane "Ianos" has affected Greece, causing damages in several territories across the country. The area mostly affected by Ianos was the Ionian Island complex and more specifically the island of Cephalonia. The road network leading to the Myrtos beach parking lot was entirely covered by soil material, which was originally constituting the surface layer of the basement rocks at the uphill areas (Figure 2). Many thousands of tons of detached soil material were found deposited across the slopes that surround the beach, altering the environment and its morphology.

Figure 2. The infrastructure suffered extensive destructions caused by material relocation which resulted severe damage due to erosional phenomena and mudflows.

The weather conditions were rather extreme during the Medicane phenomenon as a rainfall and wind mixture produced severe damages. According to the nearest meteorological station, located on Ithaki Island, the total rainfall during the two-day event of 17-18/09/2020 reached 227.4 mm, whilst the average wind speed for the same period was 21 km/h, with wind gusts of the order of 90 km/h (~10 Beauforts).

III. Data and methods

The first -out of two- flight survey was carried out before the Medicane and more specifically on July 18th, 2020, using a commercial multi-rotary UAS, which carries a Global Navigation Satellite System (GNSS) antenna with the ability of Real Time Kinematics (RTK) processing. The same equipment was used also at the post-Medicane survey, which was carried out on October 6th, 2020. The earliest survey was planned during a research project, whereas the latest survey was intentionally scheduled for acquiring comparable data, in terms of micro-topographical change detection.

Although the same flight properties were used (path, elevation, camera angle etc.), the total number of the acquired photographs was slightly different at the two surveys (Table 1) and we presume that the satellite geometry during the flights, which in turn affects the UAS camera positioning, as well as the weather (wind direction and amplitude) factor, play important roles on the amount of data, but at the bottom line there is no significant change at the overall methodology. Therefore, it took several pre-surveying flights, for planning the flying strategy to cover in a safe and satisfactory way the entire study area, due to the steep topography of the slopes surrounding the beach (Figure 3).

A DJI Phantom 4 RTK UAS had to be operated at a maximum of 385 m above sea level (ASL), after it was launched from a suitable take off area located at a beach view balcony located at 330 m ASL (Figure 4). The covered area was about 1.2 km^2.

Table 1. Flight and processing information

	July 2020	October 2020
Flying Altitude	375 m	383 m
Images	595	451
Overlap	70%	70%
Dense Point Cloud	~77 million	~74 million
Camera Location RMSE	1.5 m	0.009 m

Figure 3. South-Westwards view of Myrtos beach, which is covered by transferred material after the Ianos Medicane.

Figure 4. The DJI Phantom 4 RTK UAS at the take-off area.

The on-board GNSS receiver, antenna, and an inertial measurement unit (IMU) calculate the absolute camera positions and altitudes directly with high accuracy measurements (Klingbeil *et al.*, 2017; Grayson *et al.,* 2018).

The preflight planning included the setup of the flight routes and elevation above the take-off area, the image acquisition angle, the front, and side overlap between the successive aerial photographs, the UAS speed during the flight, as well as the camera function details. Additionally, setting up the connectivity with the GNSS base station network is also a crucial point for taking advantage of the RTK ability and consequently increase the positioning accuracy during the data acquisition phase, even if the error would be largely minimized during the photogrammetric processing phase.

The quality of the camera (FC6310R, 20Mpx, 8.8 mm focal length) does not require the UAS to stop at waypoints for taking oriented photographs for avoiding motion blur in images due to possible short-term compensating UAS movements and therefore excluding many of them at the quality control phase during the processing was not necessary.

A serious effort to keep the Ground Sampling Distance (GSD) as low as possible was made but the site topography conditions did not allow to succeed values better than 6-8 cm, at the areas with severe damages, which was rather satisfactory for the specific use of the final products.

The imagery was acquired with the camera set at an off-nadir position and this 90^{o} angle was steady due to the UAS built-in gimbal. The flight plan was set for keeping an image overlap of 70% forward and 70% side as this was calculated by the flight mission software.

The photogrammetric processing was carried out twice, for the pre- and post-Medicane periods. It was based on the Structure-from-Motion (SfM) approach and implemented using the commercial software Agisoft Metashape Professional (1.7.5 build 13229). The processing requires the alignment of the aerial images and the creation of a sparse point cloud, followed by a regular mesh generation, which was used at both flight projects.

The differentiation between the two projects comes right afterwards at the processing workflow and it has to do with the co-registration of the results of the two periods (before and after the Medicane damages) and the need for higher precision of both outcomes. Several techniques, each one with its pros and cons, are used for the determination of surface deformation features as well as for the calculation of changes within the prone area covered by mudflows accompanied by volumetric differences from the multi-temporal DSMs (Rossi *et al.*, 2018).

Therefore we chose the post-Medicane survey as the reference project since the non-destructed areas could be identified at both projects and used as tie-points between them. This is a very important barrier that needs to be overcome for creating a successive multi-temporal image after co-registering the final products very accurately (Vassilakis *et al.,* 2020).

We chose the Network RTK (NRTK) approach for georeferencing the latest survey as this is a rather accurate and less time-consuming data acquisition technique but connectivity problems during the flight led us to adopt the Post Processing Kinematics (PPK) approach during the processing, by including GNSS permanent stations' RINEX data within the procedure (Panagiotopoulou *et al.*, 2020). The succeeded accuracy was more than satisfactory, reaching horizontal and vertical errors of the order of 0.009 m yielding a very reliable dataset from the geolocation point of view.

The procedure continued with generating a dense point cloud, therefore creating much finer topographic details. At a later step a texturing was also applied before generating the final ortho-image as well as the DSM (Mancini *et al.*, 2013). Even though the NRTK approach was also chosen for the earliest survey too, the need for co-registration led us to also use GCPs within the processing. By applying this technique we managed to succeed the highest precision between the two projects by picking 7 points on the post-disaster ortho-image, which remained unchanged after the Medicane, for using them as pseudo-GCPs (Peppa *et al.*, 2018) during the photogrammetric procedure of the pre-disaster project (Figure 5).

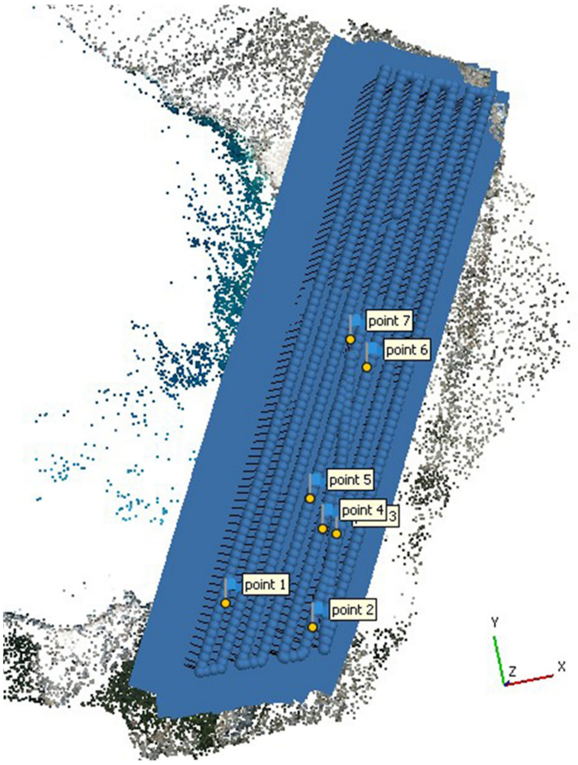

Figure 5. The locations of the UAS camera during an aerial photography survey along with the selected pseudo-GCPs, during the photogrammetric processing.

The camera calibration stored within the acquired image metadata, at both surveys, was found to be very sufficient for correlation within the photogrammetry processing, since the average error did not exceed 0.38 pixels. The pseudo-GCPs are used in the reference-dataset to easily bring the target-dataset at the exact same position with an error of 0.007 m which is rather satisfactory. The post-Medicane ortho-image was used for recording the X and Y coordinates, whilst the interpolated DSM was used for the extraction of every GCP elevation. The photogrammetric processing for both surveys led to the production of high-quality dense point clouds, consisting of about 75,000,000 points each (Table 1). Each point of the cloud includes information about the reflectance at the visible (RGB) spectra along with X, Y, Z coordinates (Westoby *et al.*, 2012).

By making spatial raster calculations between multi-temporal DSMs of the same study area, especially when acquired after a specific event that has significantly altered the surface morphology (*e.g.* flood, earthquake, mass movement), a new dataset called “DSM of Difference” can be created. The latter might be used for the quantification of any spatial alterations because of the natural event on the study area’s morphology (Williams, 2012). Volumes of moved material can be calculated, providing useful information for the researchers on the damage control and the protection measures that should be obtained for further fortification of the affected area, in order to prevent similar disaster in the future.

IV. Results

The calculation/quantification of the detectable changes between the July and October surface was accomplished with the use of multiscale model-to-model cloud comparison-precision maps algorithm (M3C2-PM). The M3C2 algorithm computes directly the distance from a reference point cloud (PC1) to a target point cloud (PC2) and by including the ‘precision maps’ is not necessary to contain roughness estimates (Niethammer *et al.*, 2011). This technique is ideal considering point clouds generated by photogrammetric processing (James *et al.,* 2017). Performing this point analysis directly on the point clouds, removes the factors that can affect the result by converting data into a DSM, which could have a major impact on the study result considering the magnitude of the changes that are measured.

According to the data from the Ithaki meteorological station, no other significant weather phenomena occurred during this period, so we can assume that all the deformation observed is due to the studied Medicane. Most of the prone area, which hosts the road leading to the beach, was covered in debris from upstream (Figure 2), revealing large mudflows and debris cones caused by heavy rainfall during the Ianos event. The mass movement is more than clear by observing the post-event ortho-photo and in terms of quantification it can be demarcated quite effortlessly leading to an accurate measurement of the area covered by mudflow (Figure 6).

The described approach could be applied for detecting changes of the order of a few decimeters, and it is rather accurate since a total area of 59,419 square meters has been altered after the storm and 40,678 square meters have been covered with mud, mainly in the central part of the area.

A total area of 6,618 square meters located in the parking lot was covered with soil material, representing an estuary of a relatively small river trending SE-NW.

In addition, Medicane Ianos weather event caused highly dynamic changes on slope surface related to massive changes in soil loss and deposition rates. The M3C2 comparison resulted a total volume of difference of 45,575.05 (±8,247.79) cubic meters, mainly at the central part of the studied area (Figure 7).

More specifically, it was calculated that a volume of 15,318.73 (±3,158.05) cubic meters were deposited at new locations within Myrtos beach and 30,256.33 (±5,089.74) cubic meters were removed from their original location, in which they were found before Ianos. The latter indicates the filling volume needed in the reconstruction process.

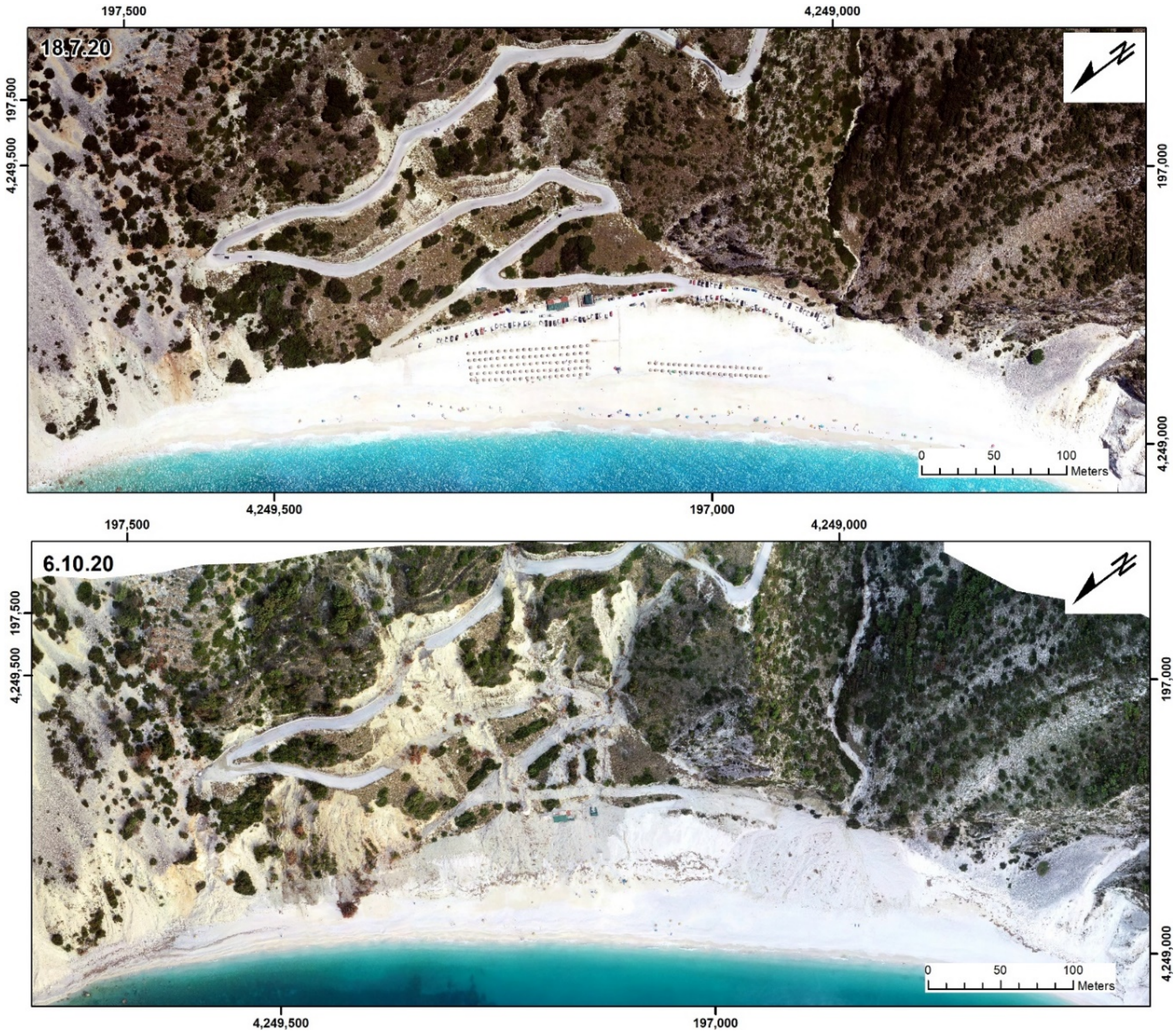

Figure 6. Ortho-photo-mosaics of Myrtos beach before (upper) and after (below) Ianos. The traces of mudflows are clear at the latest image. The road to the beach and the parking lot are almost destroyed and the surface changes are more than detectable and measurable in two dimensions.

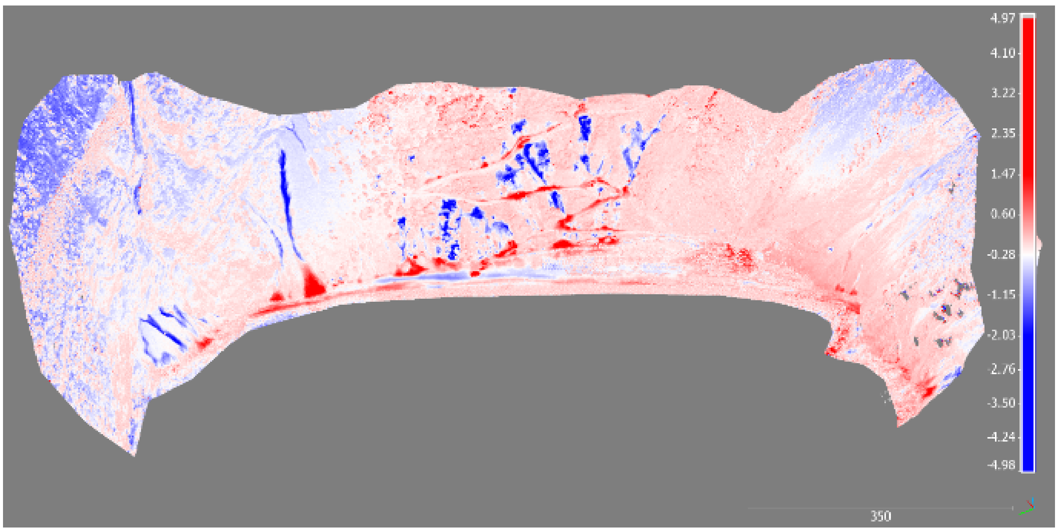

Figure 7. The point cloud comparison results across the Myrtos surrounding slopes showing areas of high incision (bluish) and deposition (reddish) of transported soil material due to Ianos.

V. Conclusions

The purpose of this research is the comparison of point clouds of the Natura protected Myrtos beach attributed to different periods after pounded by the severe Ianos Medicane. The described UAS-based methodology presents a quite simple and convenient way of comparing datasets of different time periods and achieving a co-registration of very high accuracy by using pseudo-GCPs.

The accuracy in the final photogrammetric product - including the co-registration between multi-temporal datasets- proved to be very crucial in terms of accurate results in measuring distances between the original point clouds and eventually the volume of mass movement through mudflows which leads consequently, to the quantification of the surface alteration.

Even though the UAS data collection proved to be quite challenging, in terms of both weather conditions and coverage of a quite large area, high quality results were obtained. Additional difficulty comes from handling of large datasets and the requirements in terms of computational resources to reduce processing time.

VI. Acknowledgements

This research was partially funded by the Special Account for Research Grants of the National and Kapodistrian University of Athens, grant number 70/4/16599.

References

Fiorucci, F., Giordan, D., Santangelo, M., Dutto, F., Rossi, M., and Guzzetti, F., (2018). Criteria for the optimal selection of remote sensing optical images to map event landslides. *Nat. Hazards Earth Syst. Sci.*, 18(1), pp. 405-417.

Granshaw, S.I., (2018). Structure from motion: origins and originality. *The Photogrammetric Record*, 33(161), pp. 6-10.

Grayson, B., Penna, N.T., Mills, J.P., and Grant, D.S., (2018). GPS precise point positioning for UAV photogrammetry. *The Photogrammetric Record*, 33(164), pp. 427-447.

James, M. R., Robson, S., and Smith, M. W., (2017). 3-D uncertainty-based topographic change detection with structure-from-motion photogrammetry: precision maps for ground control and directly georeferenced surveys. *Earth Surface Processes and Landforms,* v. 42, no. 12, pp. 1769-1788.

Karantanellis, E., Marinos, V., and Vassilakis, E., (2019). 3D hazard analysis and object-based characterization of landslide motion mechanism using UAV imagery. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* XLII-2/W13, pp. 425-430.

Karantanellis, E., Marinos, V., Vassilakis, E., and Christaras, B., (2020). Object-Based Analysis Using Unmanned Aerial Vehicles (UAVs) for Site-Specific Landslide Assessment. *Remote Sensing,* 12(11), 1711.

Klingbeil, L., Eling, C., Heinz, E., Wieland, M., and Kuhlmann, H., (2017). Direct Georeferencing for Portable Mapping Systems: In the Air and on the Ground. *Journal of Surveying Engineering*, 143(4), 04017010.

Liu, C.-C., Chen, P.-L., Matsuo, T., and Chen, C.-Y., (2015). Rapidly responding to landslides and debris flow events using a low-cost unmanned aerial vehicle. *APPRES*, 9(1), pp. 1-18.

Mancini, F., Dubbini, M., Gattelli, M., Stecchi, F., Fabbri, S., and Gabbianelli, G., (2013). Using Unmanned Aerial Vehicles (UAV) for High-Resolution Reconstruction of Topography: The Structure from Motion Approach on Coastal Environments. *Remote Sensing,* 5(12), 6880.

Mauri, L., Straffelini, E., Cucchiaro, S., and Tarolli, P., (2021). UAV-SfM 4D mapping of landslides activated in a steep terraced agricultural area. *Journal of Agricultural Engineering*, 52(1).

Mavroulis, S., Diakakis, M., Kranis, H., Vassilakis, E., Kapetanidis, V., Spingos, I., Kaviris, G., Skourtsos, E., Voulgaris, N., and Lekkas, E., (2022). Inventory of Historical and Recent Earthquake-Triggered Landslides and Assessment of Related Susceptibility by GIS-Based Analytic Hierarchy Process: The Case of Cephalonia (Ionian Islands, Western Greece*). Applied Sciences*, 12(6), 2895.

Niethammer, U., Rothmund, S., Schwaderer, U., Zeman, J., and Joswig, M., (2011). Open source image-processing tools for low-cost UAV-based landslide investigations. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci*., 38(1/C22), 1-6.

Niethammer, U., James, M.R., Rothmund, S., Travelletti, J., and Joswig, M., (2012). UAV-based remote sensing of the Super-Sauze landslide: Evaluation and results. *Engineering Geology*, 128, pp. 2-11.

Panagiotopoulou, S., Erkeki, A., Antonakakis, A., Grigorakakis, P., Protopapa, V., Tsiostas, G., Vlachou, K., and Vassilakis, E., (2020). Evaluation of Network Real Time Kinematics contribution to the accuracy/productivity ratio for UAS-SfM Photogrammetry. In: *Proc. of The European Navigation Conference*, ENC 2020, Dresden, Germany.

Peppa, M.V., Mills, J.P., Moore, P., Miller, P.E., and Chambers, J.E., (2019). Automated co-registration and calibration in SfM photogrammetry for landslide change detection. *Earth Surface Processes and Landforms*, 44(1), pp. 287-303.

Rossi, G., Tanteri, L., Tofani, V., Vannocci, P., Moretti, S., and Casagli, N., (2018). Multitemporal UAV surveys for landslide mapping and characterization. *Landslides*, 15(5), pp. 1045-1052.

Seier, G., Sulzer, W., Lindbichler, P., Gspurning, J., Hermann, S., Konrad, H.M., Irlinger, G., and Adelwöhrer, R., (2018). Contribution of UAS to the monitoring at the Lärchberg-Galgenwald landslide (Austria). *International Journal of Remote Sensing*, 39(15-16), pp. 5522-5549.

Turner, D., Lucieer, A., and De Jong, S.M., (2015). Time Series Analysis of Landslide Dynamics Using an Unmanned Aerial Vehicle (UAV). *Remote Sensing,* 7(2), pp. 1736-1757.

Vassilakis, E., Foumelis, M., Erkeki, A., Kotsi, E., and Lekkas, E., (2020). Post-event surface deformation of Amyntaio slide (Greece) by complementary analysis of Remotely Piloted Airborne System imagery and SAR interferometry. *Applied Geomatics,* 13(1), pp. 65-75.

Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J., and Reynolds, J.M., (2012). 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*, 179, pp. 300-314.

Williams, R.D. (2012). Section 2.3.2: DEMs of Difference. In: *Geomorphological Techniques (Online Edition),* British Society for Geomorphology; London, UK. ISSN: 2047-0371.

Zhang, H., Aldana-Jague, E., Clapuyt, F., Wilken, F., Vanacker, V., and Van Oost, K., (2019). Evaluating the potential of post-processing kinematic (PPK) georeferencing for UAV-based structure- from-motion (SfM) photogrammetry and surface change detection: *Earth Surf. Dynam.*, v. 7, no. 3, pp. 807-827.