A STRATEGY FOR DETECTION AND MEASUREMENT OF THE CLIFF RETREAT IN THE COAST OF ALGARVE (PORTUGAL)

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ABSTRACT

Sea cliff retreat is mainly caused by the occurrence of slope mass movements of different types and dimensions, which are a significant constraint for human activities and a source of considerable natural risk.

With the increasing use of cliffy coastal areas in recent decades, mainly with urban areas and leisure resorts, this problem has growing importance in many areas of the world, in terms of natural risk reduction and of related environmental, landscape and heritage preservation issues.

The Algarve cliffs were covered by detailed studies based on systematic comparison of aerial photos from 1947 to 1991 performed with simplified methods. The inventory built with the gathered information provided a very rich database allowing modelling the cliff retreat, but did not enable the assessment of the measurement errors involved.

To set up methods for cliff instability identification and measurement with the required accuracy, a photogrammetric study was made in the 16 km long Burgau-Lagos cliff dominated coast in southern Algarve in order to achieve 3D results of the morphology changes.

Several aerial surveys covering the area are available having different dates, scales and quality. The available complementary information includes camera calibration certificates for the more recent surveys and a set of ground control points identifiable in the 2002 flight.

First results of this study allowed establishing a reference status of the coast based on the ground control information of 2002. Several events that were already mentioned in the inventory dating from 1991 were correctly detected as well as new events occurred in the period 1991- 2002.

INTRODUCTION

Sea cliff retreat is mainly caused by the occurrence of slope mass movements of different types and dimensions constituting a significant constraint for human activities and a source of considerable natural hazard.

The increasing use of cliffy coastal areas in recent decades, not only with leisure resorts, but also with urban areas including high buildings, turned the cliff retreat in a problem with growing importance in several areas of the world. Natural risk reduction, landscape and heritage preservation and related environmental issues request coastal monitoring to derive scientifically based planning regulations and to support the project of prevention/stabilization measures as well as monitoring their performance.

By analogy with landslide hazard assessment (i)(ii)(iii), cliff instability hazard assessment should include spatial, time and magnitude components. These are mainly computed with empirical models based on the analysis of systematic inventories of past events, which are scarce in the literature (iv) (v) (vi).

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The Algarve cliffs (Portugal) are one exception. They were covered by detailed studies based on systematic comparison of aerial photos dating from 1947 to 1991 (v) (vii) (viii) performed with simplified methods (ix). The used methods provided a very rich database, upon which a cliff retreat model could be established. Nevertheless the results are very dependent on the skill of the operator who acquired the data. Furthermore the method does not enable a continuity of the assessment with the required objectivity and measurement accuracy.

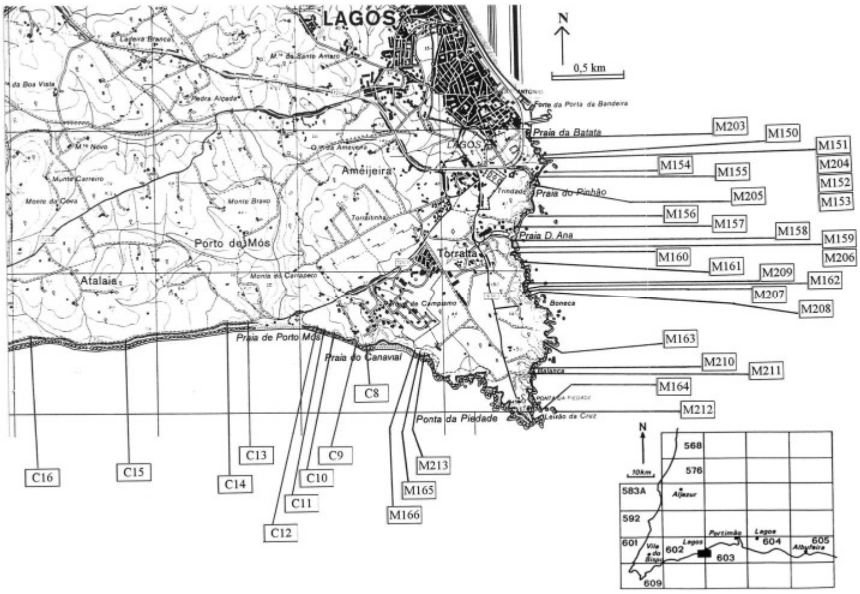

Figure 1- Example from the 1991' inventory of cliff movements (viii) in the Algarve

To overcome these problems and to set up objective methods for cliff instability identification and measurement with the required accuracy, photogrammetric procedures were tested.

From the 75km long coast strip inventoried 1991, a small part was chosen for the first experiments. A photogrammetric study was made in the 16 km long Burgau-Lagos cliff dominated coast in southern Algarve. From west to east, the cliffs are composed by alternating beds of Cretaceous marly limestone and marls, overlain by Miocene weak calcarenites, heavily affected by karst features, which are partially filled with Plio-Pleistocene sandy deposits. The cliff height is variable between 20 m and more than 100 m, and corresponds mainly to irregular cross profile slopes, with a general dip of 60º to 80º in the Cretaceous rocks, and near vertical with frequent overhanging sections in the Miocene rocks.

The frequency of cliff instabilities is not very high (45 events between 1947 and 1991), providing average cliff retreat rates of 10^{-2} to 10^{-3} m/year. As an indication of the magnitude of the cliff failures to identify and measure, the horizontal area lost at the cliff top in each event varied between 3 m^2 and 76 m^2, and volumes of displaced material between 50 m^3 and 12000 m^3.

Figure 2- Aspect of the cliffs in the test region (near Lagos)

The chosen region represents the most complicated one from the whole southern coast in terms of discontinuities of relief due to the very complex geomorphology of the sea cliffs. The aim of this first study was to establish and evaluate a strategy to automatically detect events of the above dimension occurred between two epochs, providing the location, the amount of lost area on the top of the cliff and the volume of the displaced mass of rocks and soils. The dating of each event can be achieved by nesting the available dated flights until a significant difference in the morphology in a particular location appears. Dating accuracy varies according to the time interval between both aerial surveys before and after the event.

A photogrammetric approach for the measurement of the cliff retreat is a multi-temporal task with many unusual aspects needing special consideration. The quality of the results depends not only on the temporal resolution of the data but also and mainly on the quality of the photos and complementary information. Especially older aerial surveys tend to be problematic from this point of view. Although highly important as a testimony of how it was like five or six decades ago, they are often not suitable for photogrammetric studies, since calibration data or fiducial marks are not available. Another problem is the fact that most of the available flights were planed for other purposes, presenting therefore inconvenient scales or flight directions for this kind of study. Furthermore, the 3D evaluation of the sea cliff retreat involves the generation of DEMs. A cliff region presents a difficult surface behaviour to be modelled by a DEM algorithm. So, different approaches have to be applied to it in order to find the most suitable.

DETECTION OF SEA CLIFF INSTABILITIES

Following strategy is being applied for the automatic detection of occurred land slides or rock falls (events) by means of Photogrammetry. First of all, the existence of aerial photo coverages from several epochs is required. The spatial orientation of the flights has to be determined by aerotriangulation. Having the spatial orientation of each photo, digital elevation models for each epoch can be calculated. So that automatic DEM algorithms based on stereo correlation are able to produce suitable relief models of the cliffy coast, a great amount of break lines and filter resistant points has to be previously stereo plotted. After harmonizing the cell dimensions of the several DEMs and the reference coordinate systems, a difference-DEM between two epochs reveals the height changes in the coast strip and their distribution in planimetry. A thorough interpretation of the results allows separating changes due to human activity (new buildings and roads) from those corresponding to actual events in the region of interest. A statistical analysis can then be pursued in order to quantify the movements.

Location and description of the test region

The 16 km long Burgau-Lagos strip is situated in the southern coast of Portugal. It belongs to the natural region of Algarve and is limited in the south by the Atlantic Ocean (Gulf of Cadiz). It has a predominantly west-east orientation being about 0.5 km wide landwards (fig. 3).

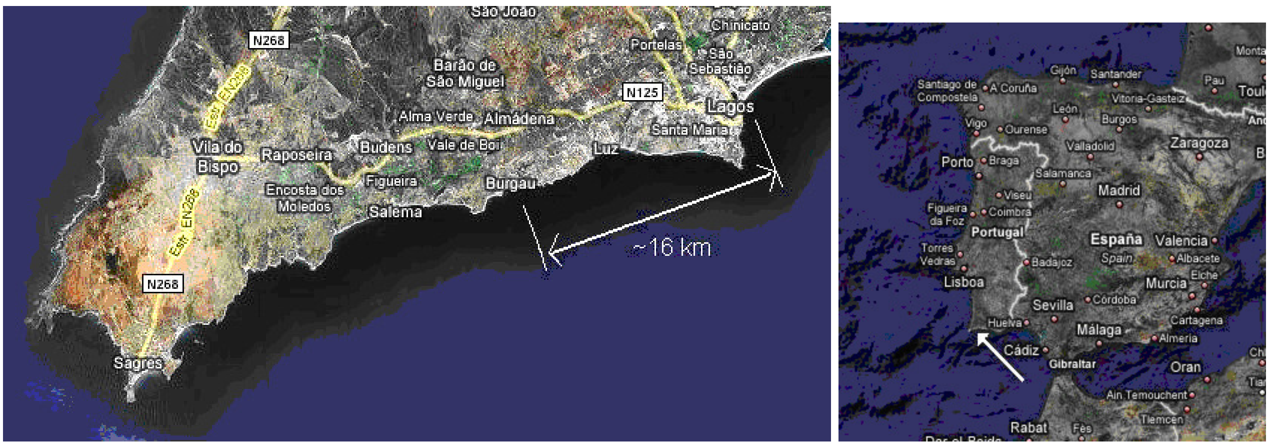

Figure 3- Burgau-Lagos coast (image Google Maps)

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Due to the geological characteristics of the terrain as well as to erosion actions, the coast is formed by near vertical to vertical cliffs with the base at the top of usually small beaches or submerged (plunging cliffs), and populated with several fallen blocks. Small sandy beaches alternate with the plunging cliffs. In the eastern extremity sinkholes and arches build a very complex morphology, a landscape that is very favourable for tourism but problematic for photogrammetry.

Aerial coverage and ground information

For the multi-temporal study of the coast, several aerial surveys were available in paper format. After considerable efforts it was possible to locate the original films and to scan them in a photogrammetric scanner Vexcel Ultrascan 5000. Unfortunately, the original film of the oldest flight couldn't be scanned, so that the existent paper prints had to be scanned for this study. Table 1 resumes the characteristics of the several aerial surveys.

Table 1: Characteristics of the aerial surveys and Ground Sample Distance (GSD) of scanned images

Name	Date	Scale	Format/ emulsion (cm x cm)	Focal length (mm)	Camera	Scanner	GSD (m)
SPLAL	**1938-1948**	1:18 000	18x18 BW (paper)	204.4	n/a	EPSONPerfection V700 Photo	0.41
RAF	1947	1:30 000	23x23 BW	154.2	Fairchild K17 (?)	---	---
USAF	1958	1:30 000	23x23 BW	152.04	n/a	---	---
DGSFA	1972	1:15 000	23x23 BW	152.05	WILDRC8	---	---
DGSUI	1974	1:15 000	23x23 BW	152.08	n/a	---	---
FAP	1980	1:15 000	23x23 BW	153.36	n/a	---	---
FAP	1983	1:30 000	23x23 Color	153.36	n/a	---	---
IGP	1991	1:30 000	23x23 BW	151.64	WILDRC10	VexcelUltrascan 5000	0.67
IGP	1995	1:15 000	23x23 BW	152.73	WILDRC10	VexcelUltraScan 5000	0.34
INAG	**2002**	1: 8 000	23x23 Color	153.073	WILDRC20	VexcelUltraScan 5000	0.18

Most of the photos had been already analysed and interpreted during the study ending in 1991 (viii). However, no other spatial orientation than the approximated location in a 1:25000 map was determined. The latest flight, INAG 2002, was flown for coast mapping purposes. Therefore, a set of ground control points (GCPs) was also available. Camera calibration reports were available for all flights except for SPLAL and RAF that constitute the first known aerial coverages of the country.

Spatial orientation of the main flights

SPLAL and INAG 2002 were chosen as main flights for this study because they limit the widest available temporal window that can be analysed based on aerial surveys.

In fact the 1991 study involved SPLAL and the flights until 1991. The SPLAL flight is not precisely dated but the respective flying company existed between 1938 and 1948. It is therefore possible (and some sparse clues seem to indicate it) that it is older than the RAF flight (1947). Although part of the RAF film is already available in digital form, SPLAL presents a more favourable scale and a better radiometry being therefore preferred for the study.

The test region is covered by 8 short strips with N-S orientation. Except for the eastern one, all strips available were composed by just 1 stereo pair with 60% overlap. Side overlaps were variable, between 20% and 60% (fig.4).

SPLAL presented several problems regarding internal orientation: no calibration information except for the camera focal length registered on the photos; fiducial marks not visible in every photo; visible distortions in some photo prints. Furthermore, there are no documented GCPs for this flight and half of the photos show 70% to 90% of water.

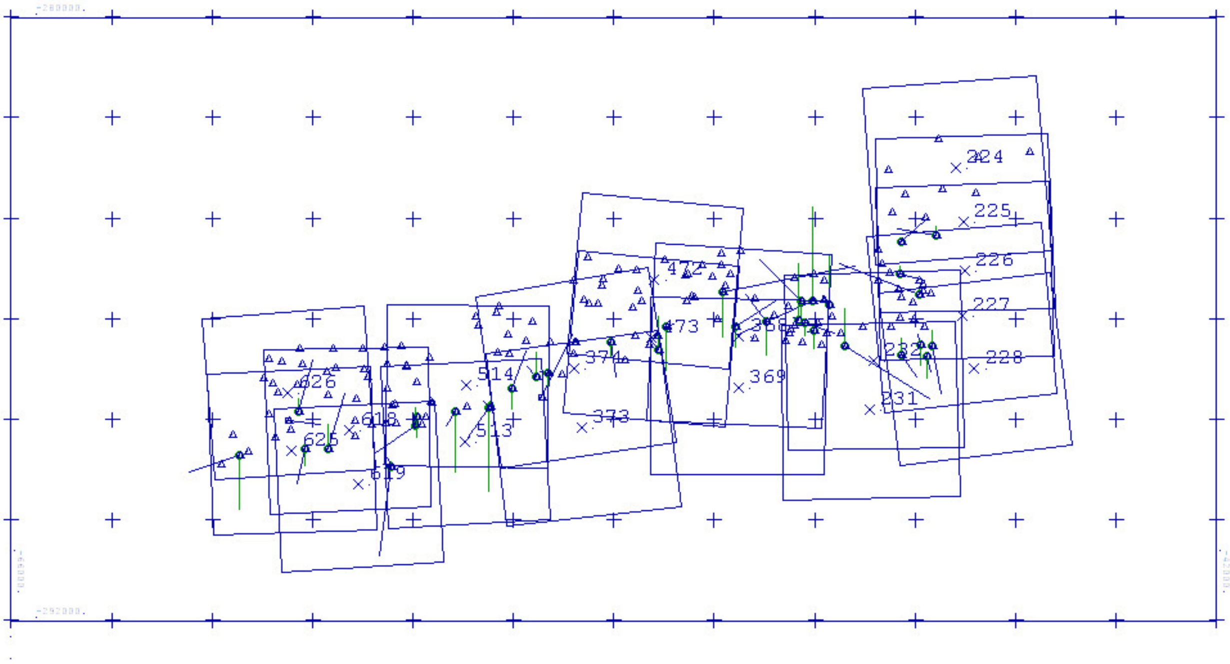

Figure 4 - SPLAL flight over the test region showing tie and control points

To recover the interior orientation of the photos, a strategy had to be applied in order to overcome the existing failures. Since the white spot of the fiducial marks was not visible in every photo and the nominal coordinates were unknown, another set of symmetrical points that could be measured in each photo has been defined (fig.5). The new set was measured in 56 scanned photos in order to obtain mean values for the photo coordinates of each mark. Using these values for the fiducial marks' coordinates and the printed focal length a pseudo-camera was built. Neither radial distortion nor principal point offset could be considered.

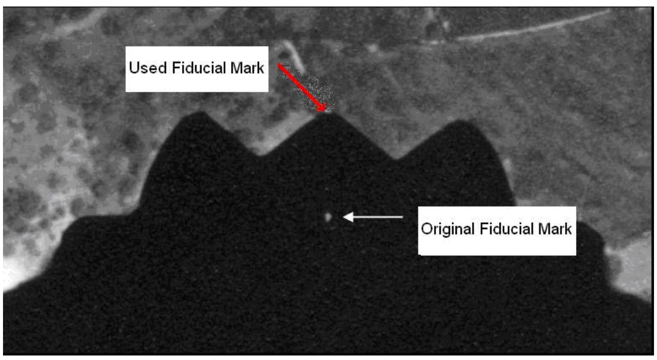

Figure 5 - Redefined fiducial marks in SPLAL

INAG 2002 has the better GSD of all flights (about 0.18 m), and a set of 30 documented and identifiable ground control points. The test region is covered by 7 strips with variable orientation along the coast and 60% endlap. The strips overlap in two models at the extremities (fig.6).

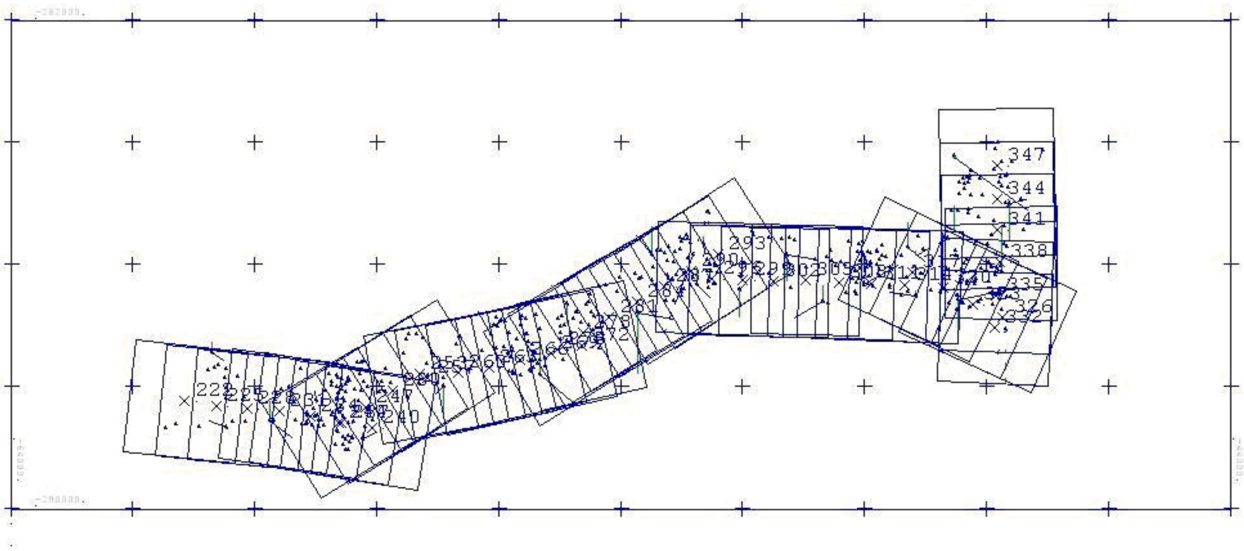

Figure 6 - Flight INAG 2002 over the test region showing pass points and ground control points

Although *pugs* are present in all strips being visible in every second scanned photo, they couldn't be used as GCPs because a precise identification in the remaining photos was extremely difficult for a monoscopic measurement of the photo coordinates.

The GCPs from INAG 2002 are not identifiable in the SPLAL flight since they consist mostly of points on urban objects that didn't exist 60 years before (fig.7). Therefore, a set of 80 well distributed common points between both flights had to be identified and collected.

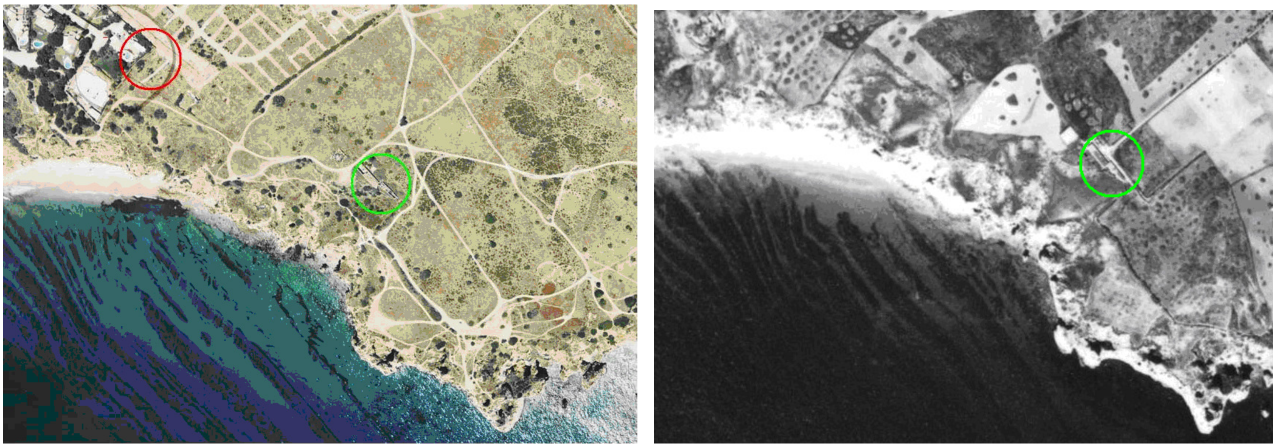

Figure 7 - The same zone in both flights: INAG2002 on the left, SPLAL on the right. Red circle: a GCP that doesn't exist in the older flight. Green circle: a common object to both epochs

Using the set of GCPs, the INAG 2002 block was triangulated by means of the software LISA/BLUH. As a result, the ground coordinates of the common points were achieved. These points were then used as ground control for an aerotriangulation of the SPLAL block. While an automatic pass and tie point extraction could be applied to the INAG 2002 block, the operation didn't work well by SPLAL due to the extension of water and to the block geometry. Especially tie points had to be collected manually. Table 2 resumes the results for both ATs.

Tabel 2: Statistical results of the aerotriangulation for INAG 2002 and for SPLAL

	AT INAG 2002	AT SPLAL (Control points resulting from AT INAG 2002)
RMSE X	+/- 0.109 m	+/- 0.800 m
RMSE Y	+/- 0.117 m	+/- 0.670 m
RMSE Z	+/- 0.258 m	+/- 1.362 m
Sigma 0	18 µm	22.56 µm
Control Points	30	36
Pixel	22.5 µm	22 µm
GSD	0.18 m	0.40 m

In view of all the adversities presented by SPLAL and the dimension of the changes to detect, the results were considered satisfactory. Except for visual evaluation, it was the first time that photos from this flight could be actually oriented and integrated in photogrammetric studies. It is to assume that the same proceeding applied to the scanned originals (instead of the prints) would yield better results for the AT.

Generation of DEMs

The strategy used so far resulted in a spatial orientation for all SPLAL photos in the same coordinate system as INAG 2002. Stereo models could be built in both flights and the top of the cliff as well as the base, where visible, have been stereo plotted. By overlapping the plotted lines of 2002 with the stereo models of the older flight, a 3D interactive sample check has been made. Discrepancies between the old cliff top and the plotted lines corresponded, in fact, to events that were already inventoried or to new movements that were clearly identifiable in the INAG 2002 photos.

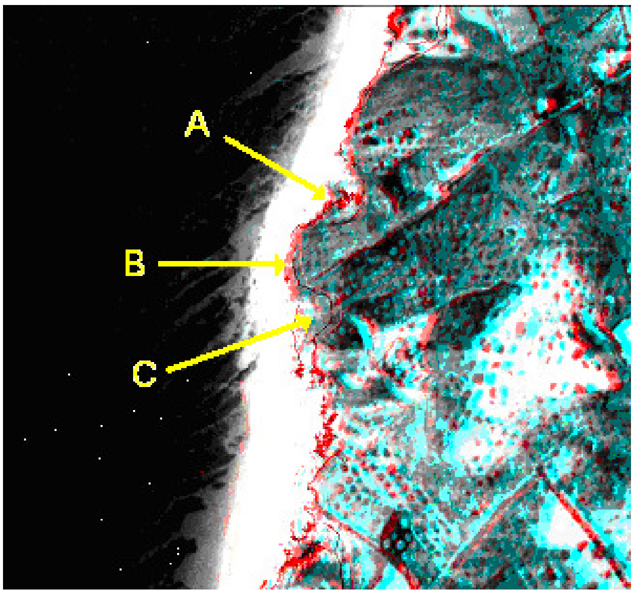

Figure 8 – (Anaglyph) SPLAL stereo model and cliff top from 2002. A and B - movements inventoried in (viii); C - large movement occurred in 1997

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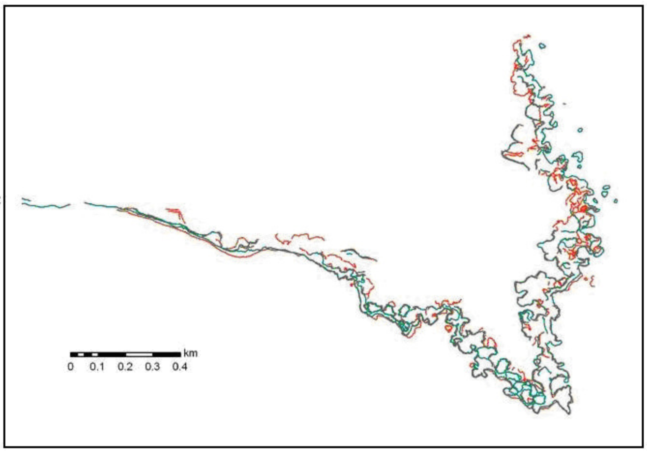

Figure 9 - Top and base of cliff lines in both epochs (red - INAG 2002, blue - SPLAL) showing considerable differences in some sites

The elevation models have been automatically generated by image correlation with the software LISA. The plotted lines were integrated as break lines. Although the image correlation algorithm applied in the extraction of tie points for the AT didn't work well in the SPLAL photos, the results of the image correlation with spatial intersection were quite good: seldom points on the sea and a dense inland point cloud. Some underwater structures near the coast have been also detected presenting false heights, due to water refraction.

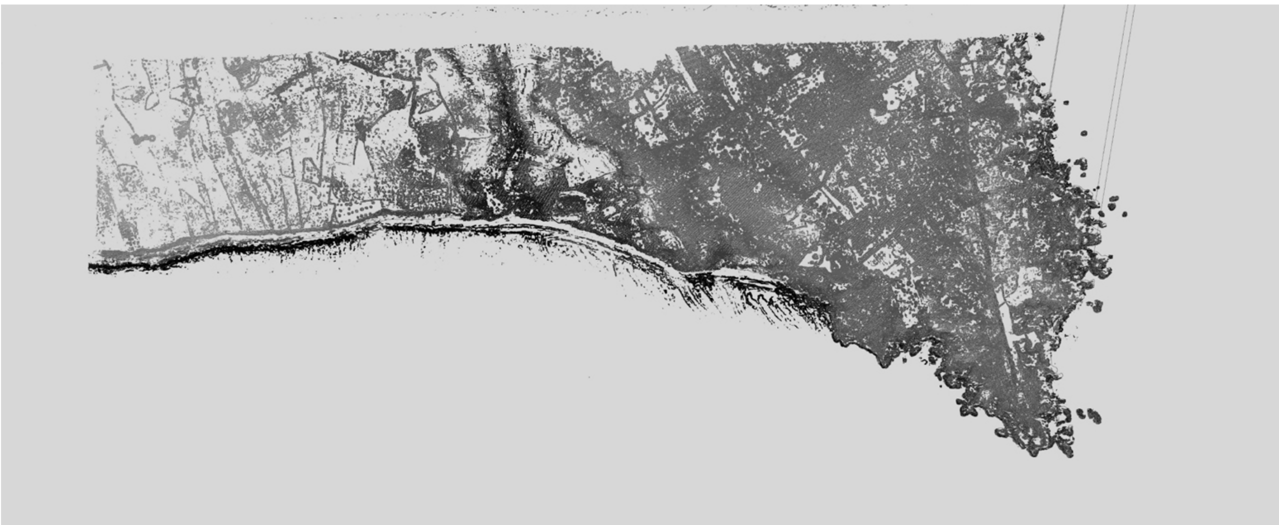

Figure 10 - DEM SPLAL point cloud

The top of the sinkholes was correctly detected but the bottom, filled with water, couldn't be correlated (fig.11). This fact showed the necessity of defining a mask with constant height (0 m) for the bottom of the sinkholes in order to avoid false heights to be assigned by the following interpolation step.

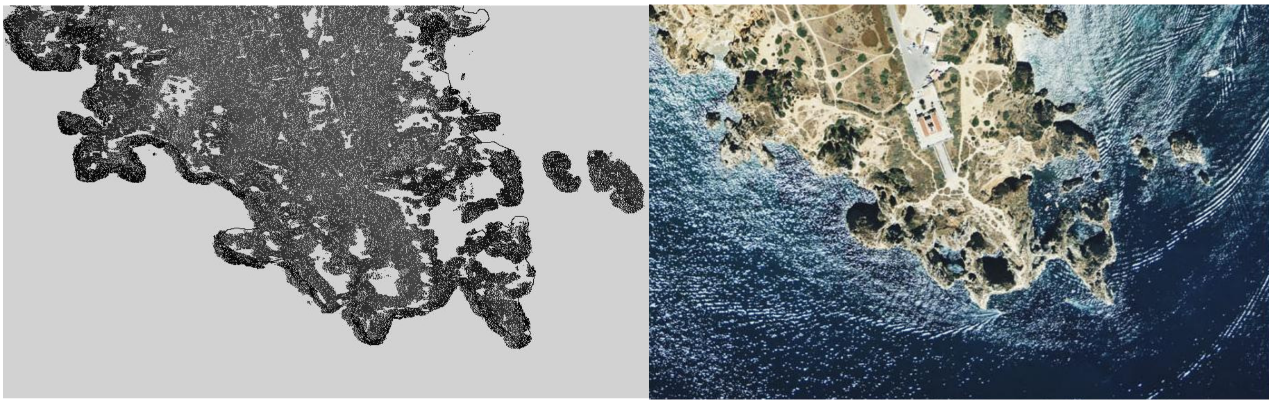

Figure 11 - Sinkholes in DEM SPLAL (left) and in INAG2002 (right)

A reference DEM was generated for INAG2002 with a resolution of 20cm. For the 3D comparison, DEMs with less resolution were used for both blocks. The optimal resolution for the comparison DEMs has to be established according to the dimension of the events to detect, the GSD of the flights involved as well as the dimension of the area to study. It is intended to use bigger cell sizes just for detecting the events in a long strip and refine the DEMs for the more accurate study of each detected event.

Finally a difference DEM could be built and interpreted. Figure 12 shows the difference between DEM INAG2002 and DEM SPLAL for a sample area. Dark red zones indicate an increase in height and dark blue and violet zones show a loss in height.

The 3D visualization was very useful in the analysis made by geologists. Anaglyphs of the stereo pairs as well as chromostereoscopic representations of the DEMs and difference DEMs were used to present results and discuss their reliability.

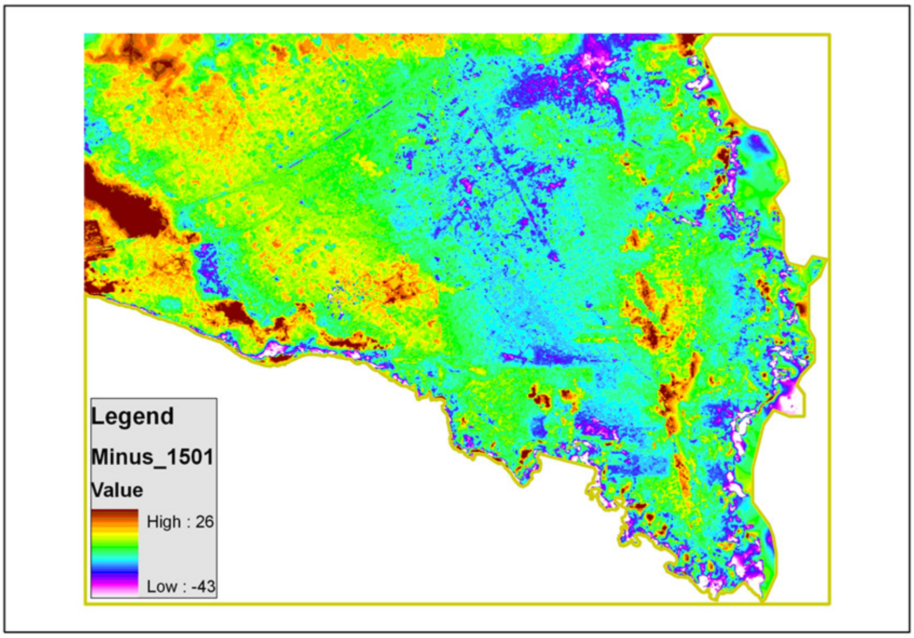

Figure 12 - Difference DEM in a 2 km x 1.8 km tile; cell size :0.55m

The overlay of an orthophoto with the difference DEM allowed interpreting the inland height changes as caused by buildings and roads not existing in SPLAL as well as some bigger volumes related with earthwork occurred in the last decades (fig.13). This analysis allowed to verify the quality of the older DEM, that was causing some uncertainty, leading to the conclusion that it was adequate for the purpose.

At the coast, an alignment of neighboured blue and red spots indicates the sites of interest for this study. In fact, for each loss in the cliff top there is mostly an increase in height on the base caused by debris deposits, except when these are taken away by man or by the waves. That explains the vicinity of blue and red in a small area.

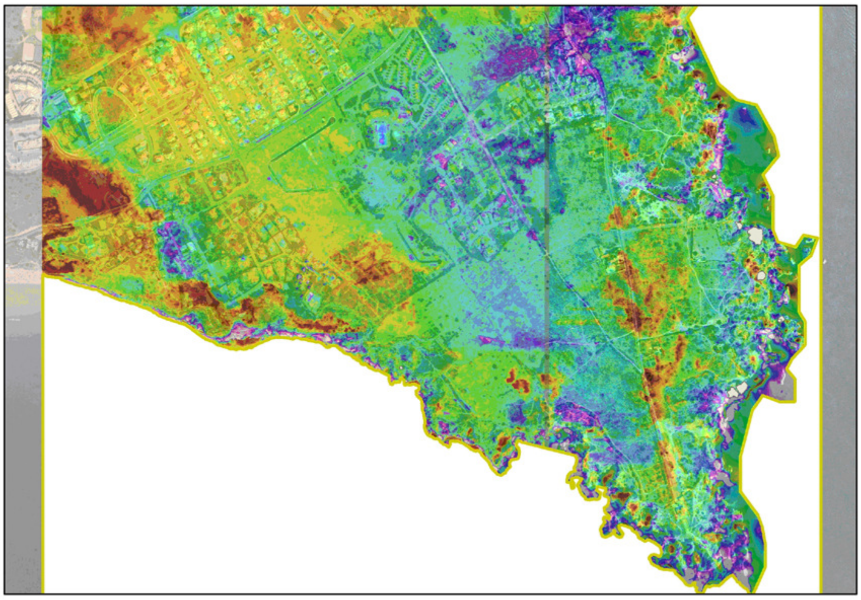

Figure 13 - Orthophotos over the difference DEM. 2 km x 1.8 km tile.

RESULTS

For a sample coastal section approximately 3.6 km long, the differential DEMs enabled the identification of several locations where cliff retreat may have occurred. From the 22 cliff retreat events identified in the1947-1991 study (viii), 19 had a full correspondence in the differential DEM, suggesting that the methods used are suitable for sea cliff and coastline evolution monitoring. The differencial DEM enabled also the detection of 23 presumably new events that require further confirmation.

The detected events are being analysed one by one, in order to confirm the instability and determine the lost area on the cliff top in the period of time between SPLAL and INAG 2002, assumed to be 54 to 64 years. Figure 14 exemplifies one type of event under analysis in Praia do Camilo. It is an intermediate dimension slope mass movement (arrows). The example shows the coincidence of the information layers from independent sources: the stereo plotted cliff top from SPLAL (dark blue line), the stereo plotted cliff top in 2002 (white line), the difference DEM showing a loss of volume (blue/violet) and the orthophoto showing how it looks like in 2002.

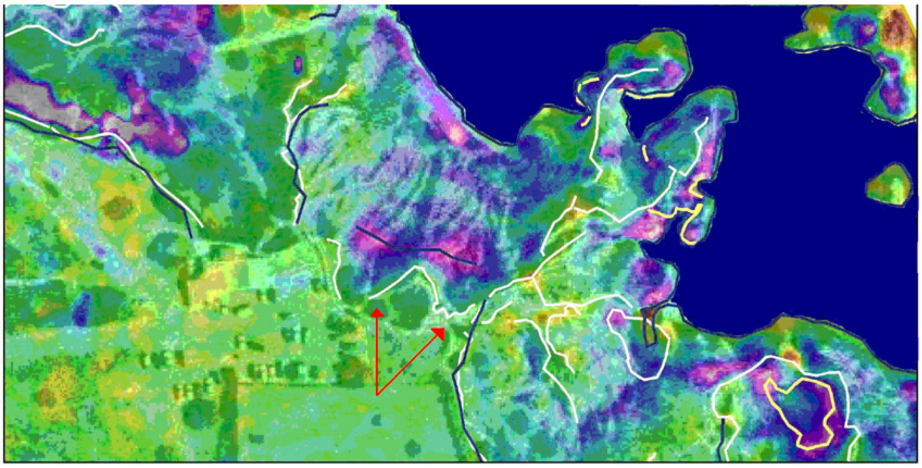

Figure 14: - Praia do Camilo: Orthophoto overlayed with difference DEM and breaklines. Dimension of the example on the ground: 120m x 70m . Lost area at the cliff top 565 m²

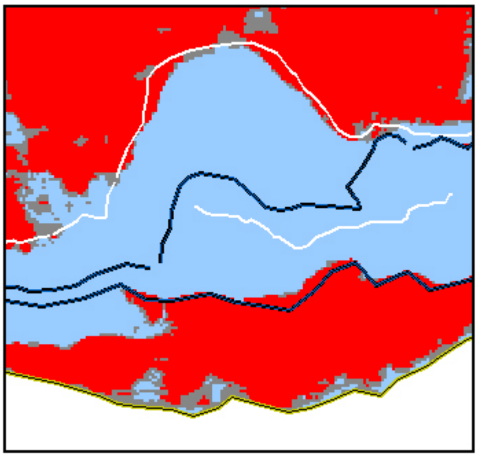

Figure 15 - Praia do Canavial – top and base of cliff 2002 (white lines) and of SPLAL(dark blue lines). Areas of lost (light blue) and gained (red) volumes. Dimension of the example on the ground: 50m x 50m. Lost area at the cliff top: 1519 m²

The difference DEM enables also the estimation of the volume of rocks and soils displaced by each event (fig. 15). These estimates are also very interesting data for other studies, mainly concerned with sources of sediments for coastal processes, including sediment near shore processing and transportation.

The results are being integrated in a database for coast management, in order to update the inventory of 1991 for the region Burgau – Lagos (fig.16). The coordinates of the inventoried events (Portuguese Datum 73) are also being corrected where necessary.

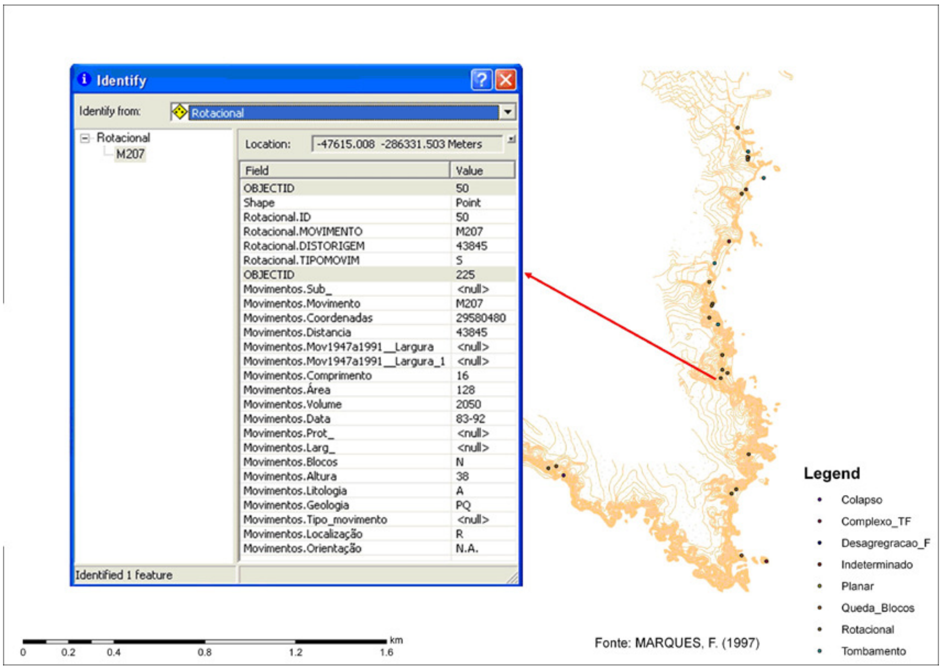

Figure 16 - Example of the constructed database showing the information related to one event.

CONCLUSIONS

The photogrammetric approach by means of multitemporal DEM generation showed to be suitable for the detection of cliff failure events in the coast of Algarve. The spatial orientation of an old aerial survey (1938-1948) could be successfully achieved and a 0.50 m² resolution DEM could be generated. The difference between two DEMs of the same region with a time gap of six decades (2002 and 1938-1948) revealed approximately 90% of the events already inventoried till 1991 and also a considerable number of new ones. Lost areas on the cliff top could be determined as well as displaced volumes for each event.

It is intended to apply the developed strategy to the entire cliff dominated coast of the Algarve covered by the available aerial surveys. A recent digital coverage of the region with suitable GSD is being acquired and will be soon integrated in the project enlarging the temporal window of the study to 6 to 7 decades.

The numeric results of this study will be used to refine the existing geological models for cliff retreat behaviour in the Algarve. The 1947-1991 inventory is being integrated in a Geographic Information System and shall be updated with the new acquired data for the events, enabling the redefinition of hazard and risk zones, in order to prevent severe accidents and to refine existing planning regulations.

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