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# SYSTEMATIC OBSERVATION OF THE CHANGE OF MARKS OF KNOWN BURIED ARCHAEOLOGICAL STRUCTURES: CASE STUDY IN THE PLAIN OF PHILIPPI, EASTERN MACEDONIA, GREECE

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## ABSTRACT

In aerial and remote sensing archaeology the determination of the best period for the image acquisition in each study area is of major importance. This allows for a large number of marks to be indentied in the selected studied area. The first step before the collection of images (archival and/or new image acquisitions) for the studied area is the identification of the Theoretically Best Period for Marks Detection (TBPMD) of the buried archaeological structures. The second step (before the supply of new image acquisitions) is to check the reliability of TBPMD. This study proposes a documentation methodology of TBPMD that is based on the results of a systematic observation (change of intensity) of marks of known archaeological structures. An image acquisitions system (remote control balloon) was used for the pilot study. Images were acquired every month for the period of one year in archaeological positions with known buried structures (Via Egnatia in the plain of Philippi, Eastern Macedonia, Greece). Analytical meteorological-climatic data of the area was collected and studied at the same time. The results of the study are encouraging, as they allow for further reduction of TBPMD in half days.

**KEYWORDS:** Aerial and Remote Sensing Archaeology, Remote Control Balloon, Systematic observation, Crop and soil mark

## 1. INTRODUCTION

The appearance of marks on the ground or on the vegetation are caused by the interaction of a buried monument (a "concrete construction", e.g. the boundaries of a building, or an "open construction", e.g. an ancient trench) with the ground or the vegetation (Figure 1).

When the probability of the existence of unknown buried monuments (e.g. near to archaeological sites or findings from excavational trial trenches) is documented in a wider area, the selection of the optimal timing of image acquisition for their detection -Theoretically Best Period for Marks Detection (TBPMD)- is based on theoretical conclusions that take into account the types and growth of vegetation, the ground types, etc (Fagan, 1959; Betti, 1963; Agache, 1963; Scollar, 1963; Jones and Evans, 1975; Wilson, 1982; Brooks and Johannes 1990; Barrett, 1993; Ciminale and Ricchetti, 1999; Featherstone et al., 1999; Hanson and Olten, 2003; Bewley, 2003; Beck, 2007; Lasaponara and Masini, 2007; Challis et al., 2009).

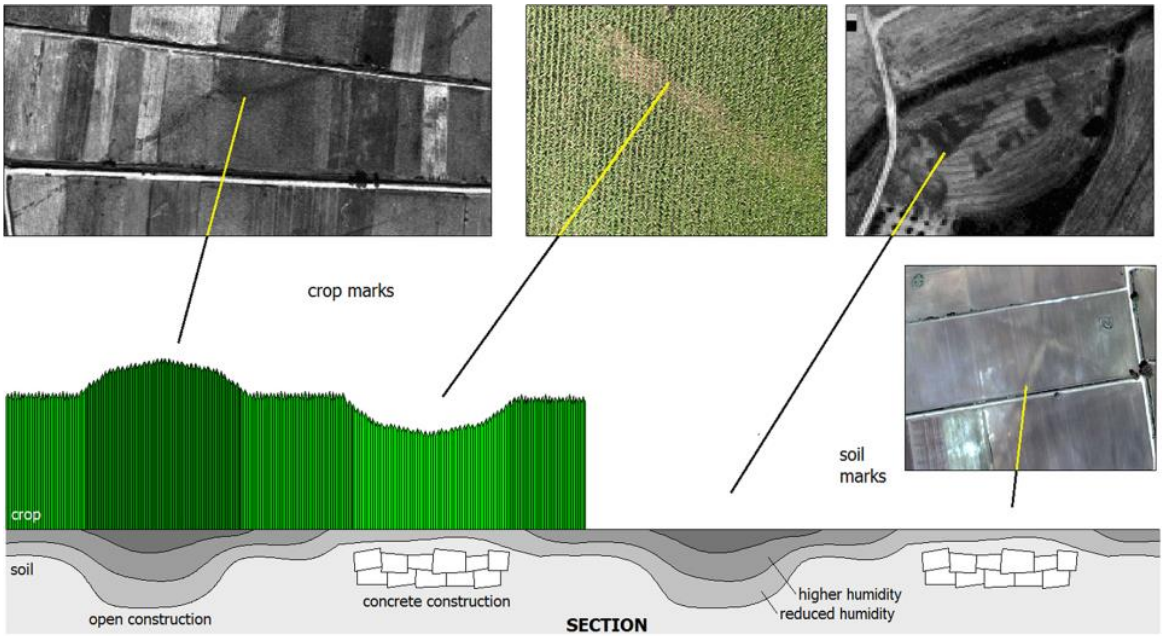


**Figure 1. Anatomy of a mark (Kaimaris, 2016)**

In aerial and remote sensing archaeology, significant efforts are made for automatic detection, digital visual enhancement of marks in images and interpretation of the phenomenon of interaction between buried monuments and the ground or the vegetation, using panchromatic, multispectral, hyperspectral sensors (Beck, 2007; Challi et al., 2009; Georgoula et al., 2004; Yang, 2007; Cavalli et al., 2007; De Laet et al., 2007; Trier et al., 2009; Ciminale et al., 2009; Verhoeven and Doneus, 2011). Also, the TBPMD is studied and analysed so that its enhancement or degradation, and its documentation or rejection is made possible through observations, before the supply of images (archival and/or new image acquisitions) for the entire studied area. Regarding this fact, a methodological approach (Kaimaris et al., 2012) suggests that the research should be conducted in a representative site (in soil composition and crop species) of a wider studied area. In this case, the photointerpretation, for example, of a small number (since it is a subarea of the wider studied area) of intertemporal satellite images will only allow the enhancement or the degradation of TBPMD.

The documentation or the rejection of TBPMD requires the systematic observation of the selected positions (within the wider studied area) that contain buried archaeological structures (known depth and type of ground and vegetation). The frequency of the image acquisitions should be at least one month and for at least one year (because the ideal frequency of image acquisition is unknown, one month is selected as the average time for the repetition of image acquisitions). By this methodology, the intensity of the observed marks can be evaluated through a large number of overlapping images taken during different time periods. Finally, the everyday collection of meteorological-climatic data for one year is also necessary. This paper concentrates on this particular aspect.

## 2. TEST AREA AND METHODOLOGY

An extensive research on aerial and remote sensing archaeology has been conducted in the region of Eastern Macedonia (Greece), from ancient Amphipolis to Philippi, , resulting in the detection of dozens of marks of buried structures (Kaimaris et al., 2008; Kaimaris et al., 2009). This research relied on the optimization of the Theoretically Best Period for Marks Detection (Kaimaris et al., 2012). Two periods were examined: (A) from mid-April to mid-May (Period A, Figure 2), and (B) from late June to late August (Period B, Figure 2). A period (C) was added from early November to late January, because it falls between the driest months and the start of the winter rains (Betti, 1963; Brooks and Johannes, 1990; Barrett, 1993; Beck, 2007).

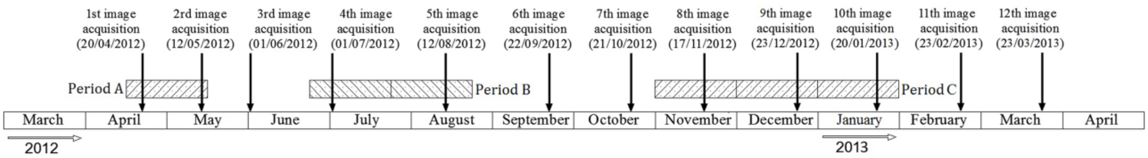


**Figure 2. Image acquisition dates. Stripes indicate the Theoretically Best Period for Marks Detection (TBPMD)**

For this paper, two positions (1 and 2: Figure 3, in red circles) of marks of the ancient Via Egnatia were selected from the wider studied area. Those marks have been documented with excavation trenches in the plain of Philippi (Karadedos and Nikolaidou-Patera, 2006). In particular, two excavation trenches (in small distance from each other, Figure 4) were conducted in Position 1, and in Position 2 one excavation trenche was conducted too (Figure 5).

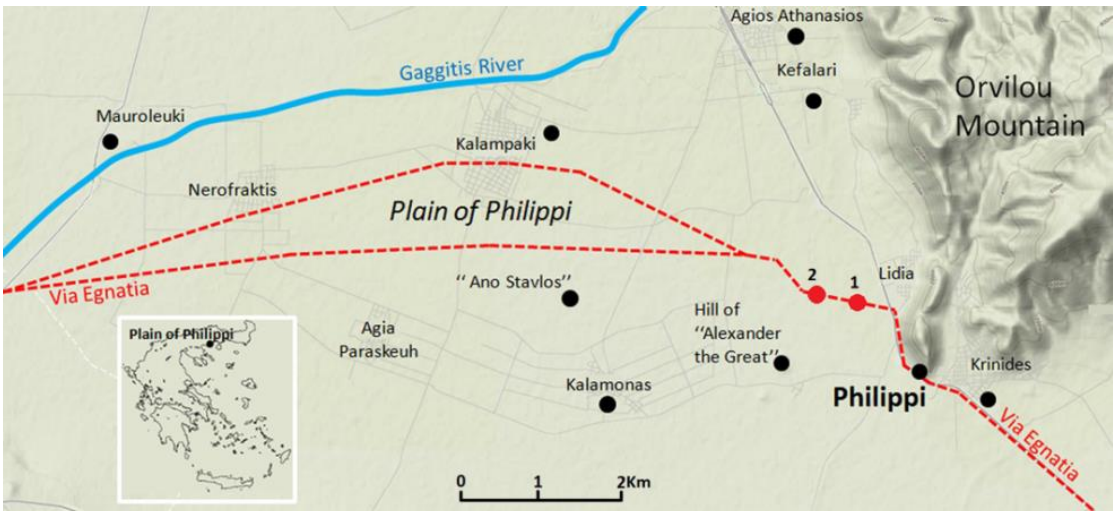


**Figure 3. In the red circles on the plain of Philippi: Position 1 and 2 of the excavational trenches of Via Egnatia. In the black circles: The settlement from the Late Neolithic period, through the Historical period and to the Roman period. With dotted red line: the path of Via Egnatia, according to the marks (north-west of the plain there are two possible paths of Via Egnatia)**

All excavation trenched sized 4.5x15m. In position 1 the depth at which Via Egnatia is found is about 1.1 m, and in position 2 about 1.6 m. Underneath the crop layer, the later repair of the road structure of thickness up to 20-30 cm is spotted. It consists of large rough stones structured together with fine, sandy, blonde soil. Plus, there is the original road surface of Via Egnatia, which consists of small rough stones (mainly marbles) with smooth upper surface due to the use of the road. The original road surface is bordered by vertical standing stones that define its width (about 5m). Slopes of gravel and breccia (with their smooth upper surface due the road's use) are spotted at the right and left of the road surface, setting the road 80 cm above the ground level (natural ground). In one of the excavation trenches in Position 2 and at the intersection of the slope with the natural ground, a marble urn was found (Figure 6) and a burial column on the base (Figure 7) with a depiction of a horseman and with latin inscription.

The crop in both Positions is corn (covers 70% of the plain of Philippi), and the soil is composed of 16% of clay (alternating with carbonaceous matter and sand) and 84% of fine-grained material (red clay and gravels). The marks that can be observed at the corn crop are not due to the depth of the corn roots (40-60 cm), which is characterized as superficial, but due to reduced humidity of the ground over the monument which does not allow the normal growth of crops. Although corn represents the largest coverage in the plain of Philippi, the final conclusions of TBPMD that will be exported, will refer to this particular area with this particular crop and fine-grained soil. The corm's height ranges from 1.5 to 2.0 m. It flourishes in atmospheric temperatures from 20°C to 38°C and in soil temperatures from 12°C to 35°C, and requires a hot and dry climate with little rainfall for its development. It is sowed in spring and harvested in late September.

**Figure 4. The two excavation trenches in Position 1 (Kaimaris, 2006).**

**Figure 5. The excavation trenche in Position 2 (Kaimaris, 2006).**

**Figure 6. The marble urn that was found next to Via Egnatia. It was moved to the archaeological museum, where it was photographed (Kaimaris, 2006).**

**Figure 7. The burial column over its base, at the spot where it was located next to Via Egnatia (Kaimaris, 2006).**

## 3. THE DATA/RESULTS OF THE PILOT SURVEY

### *3.1 Image acquisition dates*

The image acquisitions began on April 2012 and completed on March 2013 (Figure 2). A Remote Control Balloon (Figure 8 and 9) and a digital camera Canon EOS 20D (8Mpixel) were used (flight height of 150m, allows a very satisfying spatial resolution of 3cm on the ground, and a coverage of 125x185m per image).

Image acquisitions were allowed only on certain days of the week (Friday, Saturday and Sunday) according to Greek laws (flight permission was issued by the Greek Civil Aviation Authority). This resulted in failure to maintain periodic (every 30 days) repeating image acquisitions because of the weather phenomena during the flights.

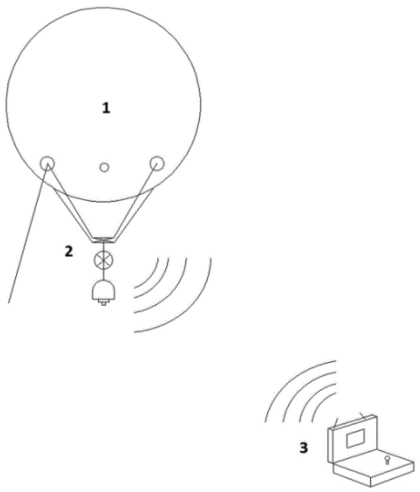


**Figure 8. The Remote Control Balloon: small-size Balloon (1), image acquisition (2) and ground station (3)**

**Figure 9. The RC Balloon during flight**

### *3.2 Meteorological-climatic data*

Severe weather phenomena can lead to the unusual appearance or disappearance of the buried marks of archaeological structures. For this reason, detailed weather-climatic data is collected every day with a sampling frequency of 10'. Thus, if the conditions are normal for the season, the marks observations in the new image acquisitions (Figure 2) are likely to be repeated with relatively similar intensities the next year (also vice versa). The meteorological station is located 5 km from the studied area, and belongs to the National Observatory of Athens (NOA), Greece.

A general conclusion from the study and the comparison of the meteorological-climatic data for a period of one year (Figure 2 and 10), with the corresponding data from the last 25 years in the same region (HNMS, 2014), is that the weather and climatic conditions were prevailingly normal for the season. Nevertheless, the meteorological-climatic data for a period of 15 days up to the time of each image acquisition will be presented in Figure 11 and will be interpreted in Table 1.

In conclusion, meteorological and climatic conditions before the image acquisitions were normal for the season for the above periods.

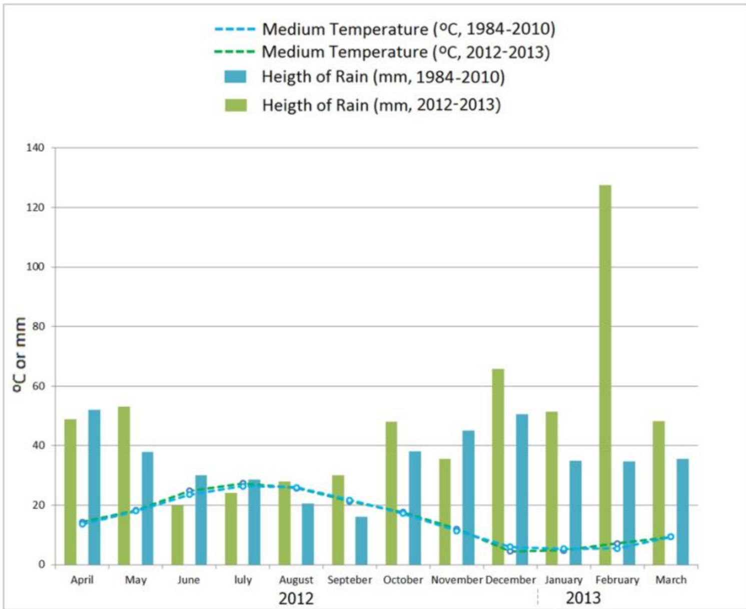


**Figure 10. Comparison of meteorological-climatic data from the 12 months of the study with data from the last 30 years**

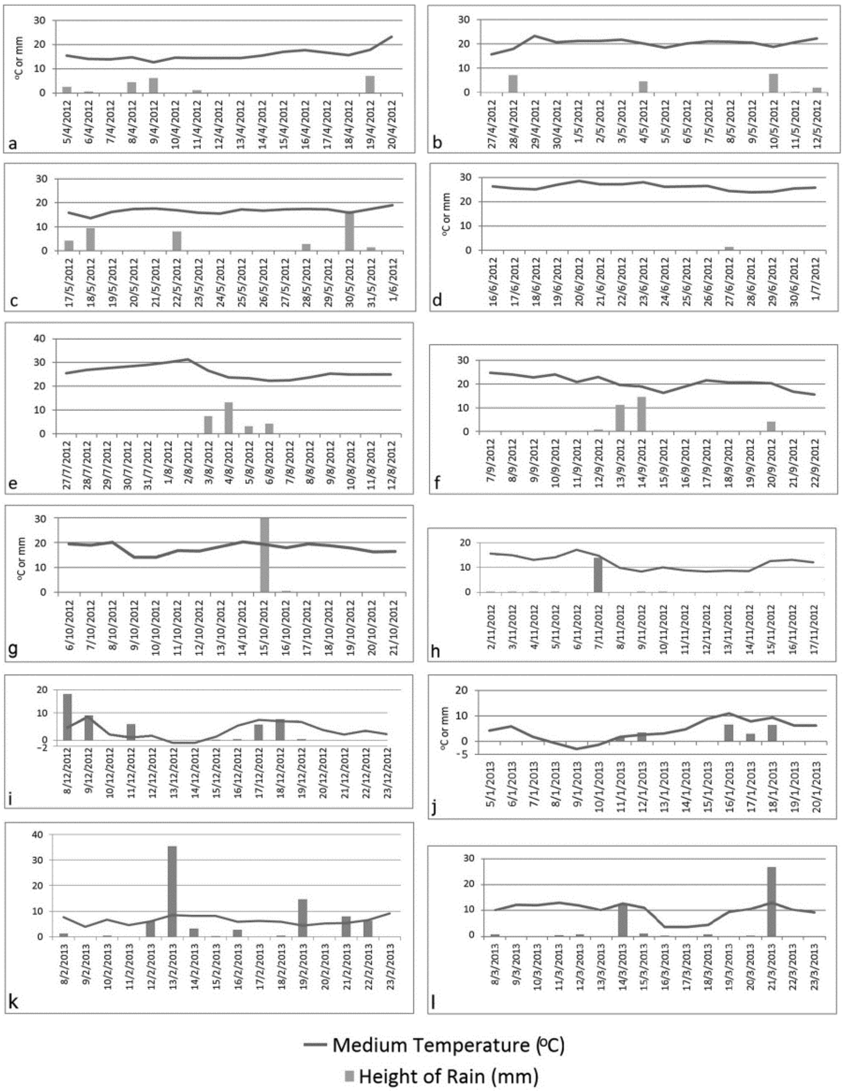


**Figure 11. Humidity, temperature and rainfall 15 days leading up to the time of each image acquisition**

**Table 1. Interpretation of meteorological climatic data for a period of 15 days leading up to the time of each image acquisition (Fig. 2, 10 and 11)**

| Period of 15 days | Temperature | Rainfall | |
|---|---|---|---|
| | | Number | Intensity |
| 05/04-20/04/2012 | normal for the season | | |
| 27/04-12/05/2012 | slightly higher | normal for the season | |
| 17/05-01/06/2012 | normal for the season | slightly higher | normal for the season |
| 16/06-01/07/2012 | normal for the season | | |
| 27/07-12/08/2012 | normal for the season | | |
| 07-22/09/2012 | normal for the season | slightly higher | low |
| 06-21/10/2012 | normal for the season | | |
| 02-17/11/2012 | normal for the season | | |
| 08-23/12/2012 | slightly lower | slightly higher | normal for the season |
| 05-20/01/2013 | slightly lower | slightly higher | normal for the season |
| 08-23/02/2013 | normal for the season | no normal for the season | |
| 08-23/03/2013 | normal for the season | | |

### *3.3 Position 1*

There was no image acquisition on July because of the strong wind. Due to the wind, only a few images were captured (with difficulty) for the month of May (Table 2). The images of positions 1 and 2 have not been digitally edited for visual improvement. Also, no geometric correction of the images was conducted. Their correlation was easy as common reference points were used, such as the agricultural roads and the boundaries of land parcels. To this direction, the absence of relief (horizontal agricultural areas) and capacity (the system) in combination with vertical images have significantly helped.

The evaluation of the intensity of observation of the mark in position 1 of the diachronic images is a combined result of the photo-interpretation of images (qualitative assessment, Figure 12) and the study of the histograms (quantitative assessment, Figure 13). More specifically, it is apparent from the images' histograms (Figure 13) that the trail is intense (Table 3), when the frequency of pixels that have the same intensity exceed the value of 1000 (axis Y, Figure 13).

From the evaluation results (Table 3), and as shown in figure 2 and tables 1, 2, at the beginning of the period A the height of the corn was low (5 cm), thus allowing for the observation of soil mark. At the end of the period A, the two-day, low-intensity rainfall, up to an hour before the image acquisition, combined with a slightly higher temperature than normal for the season, did not help in the observation of the mark in position 1. The corn was at the early stages of development and measured 45 cm. Consequently, this prevented the appearance of crop marks. Between the periods A and B, a slightly higher amount of rainfall than normal, combined with high temperatures (normal for the season), did not help in the observation of the mark at position 1. The corns of 100 cm may not have been influenced and prevented by the buried structures. At the end of the period B the corn was at its maximum height (200 cm) and had reached the stage of maturity, a fact that produced smooth contrasts between the healthy and unhealthy vegetation. Probably, if the image acquisition of 01/07/2012 had been carried out, the crop marks would have been intense. From early September to late November, as it was the end of the summer season and periods of low-frequency rainfall prevailed, the soil moisture was minimal and prevented the appearance of marks. From mid-December to late January, despite the low temperatures, which are normal for the season, the repeated rainfall (with a slightly higher frequency and intensity than normal) allowed for the appearance of marks. In February, the frequency and intensity of rainfall were not normal for the season and the soil mark was satisfactory. If the rainfall had not been so intense, perhaps the intensity of the crop mark would have been greater. In March, the frequency and intensity of rainfall were normal for the season, and the soil mark was absent.

**Table 2. Information images for the position 1**

| Image acquisition | | | | Wind speed (km/h) | Corn height (cm) | Within TBPMD | Figure |
|---|---|---|---|---|---|---|---|
| **Number** | **Date** | **Coverage** | **Time** | | | | |
| 1st | 20/04/2012 | 100% | 11:50-12:00 | 4.8 | 5.0 | Yes | 12.a |
| 2nd | 12/05/2012 | 60% | 16:00-16:24 | 11.3 | 45.0 | Yes | 12.b |
| 3rd | 01/06/2012 | 100% | 8:30-8:45 | 0.0 | 100.0 | No | 12.c |
| *4th* | *01/07/2012* | - | 8:10-8:25 | 12.5 | 200.0 | - | - |
| 5th | 12/08/2012 | 100% | 7:55-8:05 | 1.0 | 200.0 | Yes | 12.d |
| 6th | 22/09/2012 | 100% | 8:19-8:28 | 0.0 | 0.0 | No | 12.e |
| 7th | 21/10/2012 | 100% | 9:14-9:25 | 1.0 | 0.0 | No | 12.f |
| 8th | 17/11/2012 | 100% | 8:46-8:56 | 1.0 | 0.0 | Yes | 12.g |
| 9th | 23/12/2012 | 100% | 12:20-13:00 | 3.0 | 0.0 | Yes | 12.h |
| 10th | 20/01/2013 | 100% | 11:15-11:30 | 5.2 | 0.0 | Yes | 12.i |
| 11th | 23/02/2013 | 100% | 11:45-11:55 | 9.3 | 2.0 | No | 12.j |
| 12th | 23/03/2013 | 100% | 13.55-14.00 | 11.9 | 10.0 | No | 12.k |

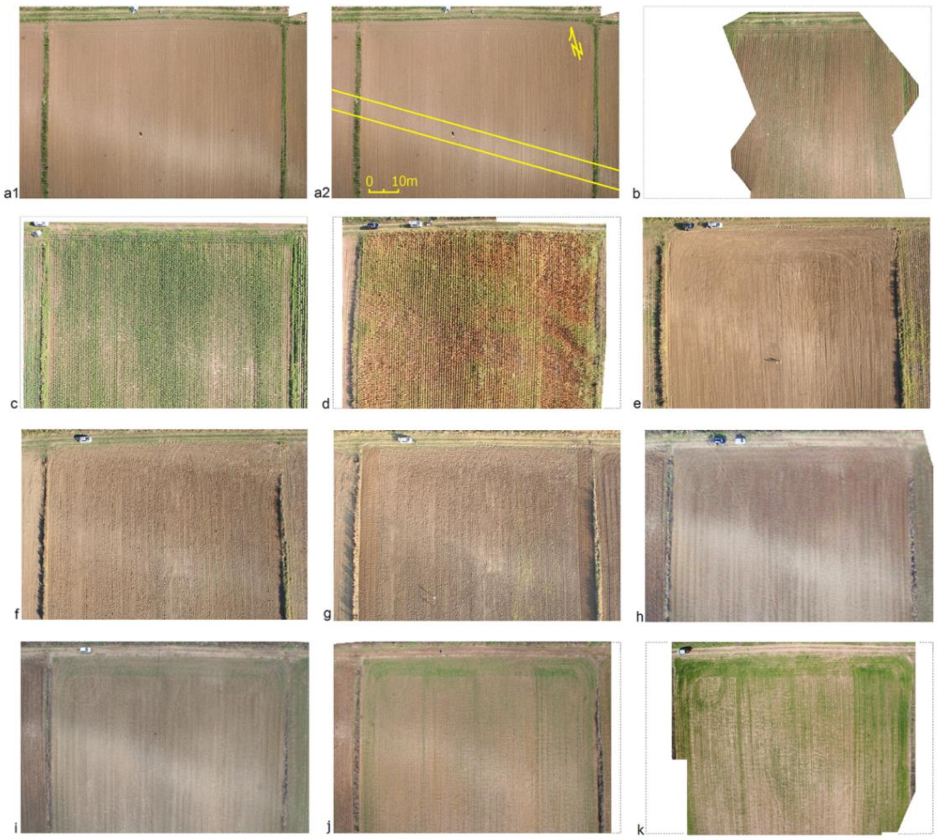


**Figure 12. a1: image acquisition 20/04/2012, a2: yellow line is the course of Via Egnatia, b: image acquisition 12/05/2012, c: 01/06/2012, d: 12/08/2012, e: 22/09/2012, f: 21/10/2012, g: 17/11/2012, h: 23/12/2012, i: 20/01/2013, j: 23/02/2013 and k: 23/03/2013.**

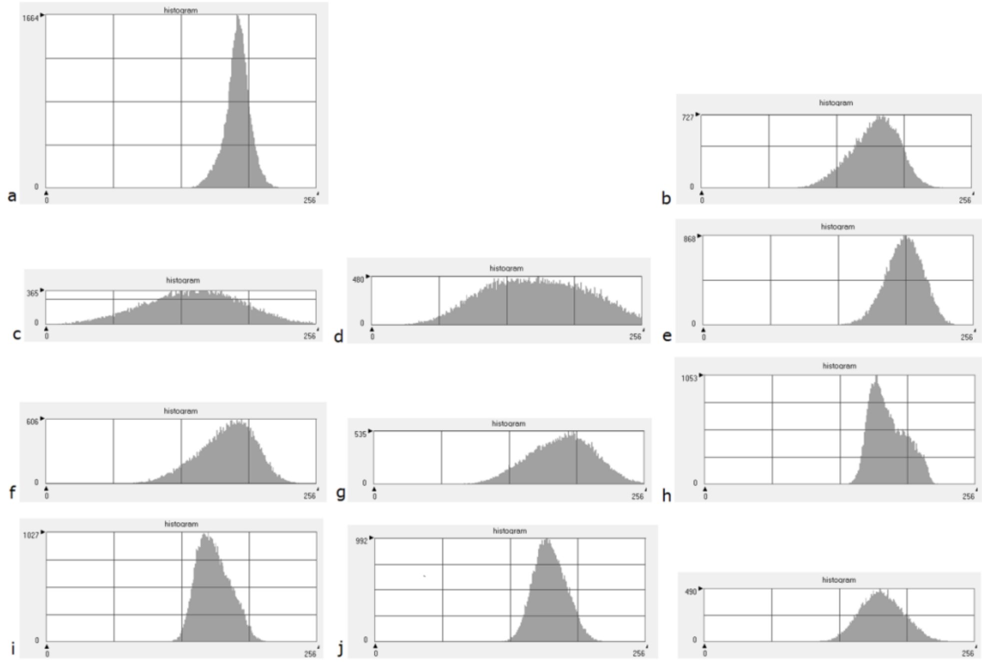


**Figure 13. The histograms of the diachronic images a: 20/04/2012, b: 12/05/2012, c: 01/06/2012, d: 12/08/2012, e: 22/09/2012, f: 21/10/2012, g: 17/11/2012, h: 23/12/2012, i: 20/01/2013, j: 23/02/2013 and k: 23/03/2013, of position 1.**

Therefore, the conclusions drawn from Table 3 below are:

- The first (period A) and third (period C) Theoretically Best Period for Marks Detection (TBPMD) provide satisfactory results regarding the intensity of marks.
- The achieved results allow a further reduction of the first TBPMD, i.e. from mid- to late April, and the third TBPMD, i.e. from mid-December to late January.
- For the soil marks (fine-grained soil) of parts in Via Egnatia, or in similar buried monuments (morphological/typological), which have not been detected so far in the plain of Philippi and located at the depth of 1.1 m, the chances detected in new image acquisitions within the above time periods are significantly increased, provided that weather and climatic conditions are normal for the season.

**Table 3. Elevation of mark intensity in observation position 1**

| Image acquisition Number | Date | Period | Within TBPMD | Mark intensity | Figure |
|---|---|---|---|---|---|
| 1st | 20/04/2012 | early A | Yes | **intense** | 12, 13.a |
| 2nd | 12/05/2012 | end of the A | Yes | almost absent | 12, 13.b |
| 3rd | 01/06/2012 | between A and B | No | absent | 12, 13.c |
| *4th* | 01/07/2012 | - | - | - | - |
| 5th | 12/08/2012 | end of the B | Yes | absent | 12, 13.d |
| 6th | 22/09/2012 | between B and C | No | almost absent | 12, 13.e |
| 7th | 21/10/2012 | between B and C | No | almost absent | 12, 13.f |
| 8th | 17/11/2012 | early C | Yes | almost absent | 12, 13.g |
| 9th | 23/12/2012 | middle C | Yes | **intense** | 12, 13.h |
| 10th | 20/01/2013 | end of the C | Yes | **intense** | 12, 13.i |
| 11th | 23/02/2013 | between C and A | No | satisfactory | 12, 13.j |
| 12th | 23/03/2013 | between C and A | No | absent | 12, 13.k |

### *3.4 Position 2*

The image acquisition for May did not take place due to strong winds (Table 4).

The evaluation of the intensity of observation of the mark in position 2 of the diachronic images is a combined result of the photo-interpretation of images (qualitative assessment, Figure 14) and the study of the histograms (quantitative assessment, Figure 15). More specifically, it is apparent from the images' histograms (Figure 15) that the trail is intense (Table 5), when the frequency of pixels that have the same intensity exceed the value of 1500 (axis Y, Figure 15).

**Table 4. Information images for the position 2**

| Image acquisition | | | | Wind speed (km/h) | Corn height (cm) | Within TBPMD | Figure |
|---|---|---|---|---|---|---|---|
| No. | Date | Cover-age | Time | | | | |
| 1st | 20/04/2012 | 100% | 13:00-13:50 | 6.9 | 5.0 | Yes | 14.a |
| *2nd* | *12/05/2012* | - | *14:00-14:15* | *12.0* | *45.0* | - | - |
| 3rd | 01/06/2012 | 100% | 9:10-9:20 | 0.0 | 100.0 | No | 14.b |
| 4th | 01/07/2012 | 50% | 10:00-10:20 | 2.7 | 200.0 | Yes | 14.c |
| 5th | 12/08/2012 | 100% | 8:30-8:45 | 4.3 | 0.0 | Yes | 14.d |
| 6th | 22/09/2012 | 100% | 8:49-8:57 | 0.0 | 0.0 | No | 14.e |
| 7th | 21/10/2012 | 100% | 8:36-8:51 | 0.0 | 0.0 | No | 14.f |
| 8th | 17/11/2012 | 100% | 9:27-9:34 | 2.0 | 0.0 | Yes | 14.g |
| 9th | 23/12/2012 | 100% | 13:50-14:00 | 3.5 | 0.0 | Yes | 14.h |
| 10th | 20/12/2012 | 100% | 13:40-13:55 | 3.2 | 0.0 | Yes | 14.i |
| 11th | 23/02/2013 | 100% | 12:10-12:30 | 10.6 | 0.0 | No | 14.j |
| 12th | 23/03/2013 | 100% | 14:55-15:05 | 11.8 | 0.0 | No | 14.k |

**Table 5. Elevation of mark intensity in observation position 2**

| Image acquisition | | Period | Within TBPMD | Mark intensity | Figure |
|---|---|---|---|---|---|
| Number | Date | | | | |
| 1st | 20/04/2012 | early A | Yes | absent | 14, 15.a |
| 2nd | 12/05/2012 | - | - | - | - |
| 3rd | 01/06/2012 | between A and B | No | absent | 14, 15.b |
| 4th | 01/07/2012 | early B | Yes | **intense** | 14, 15.c |
| 5th | 12/08/2012 | end of the B | Yes | absent | 14, 15.d |
| 6th | 22/09/2012 | between B and C | No | absent | 14, 15.e |
| 7th | 21/10/2012 | between B and C | No | absent | 14, 15.f |
| 8th | 17/11/2012 | early C | Yes | absent | 14, 15.g |
| 9th | 23/12/2012 | middle C | Yes | almost absent | 14, 15.h |
| 10th | 20/01/2013 | end of the C | Yes | satisfactory | 14, 15.i |
| 11th | 23/02/2013 | between C and A | No | satisfactory | 14, 15.j |
| 12th | 23/03/2013 | between C and A | No | absent | 14, 15.k |

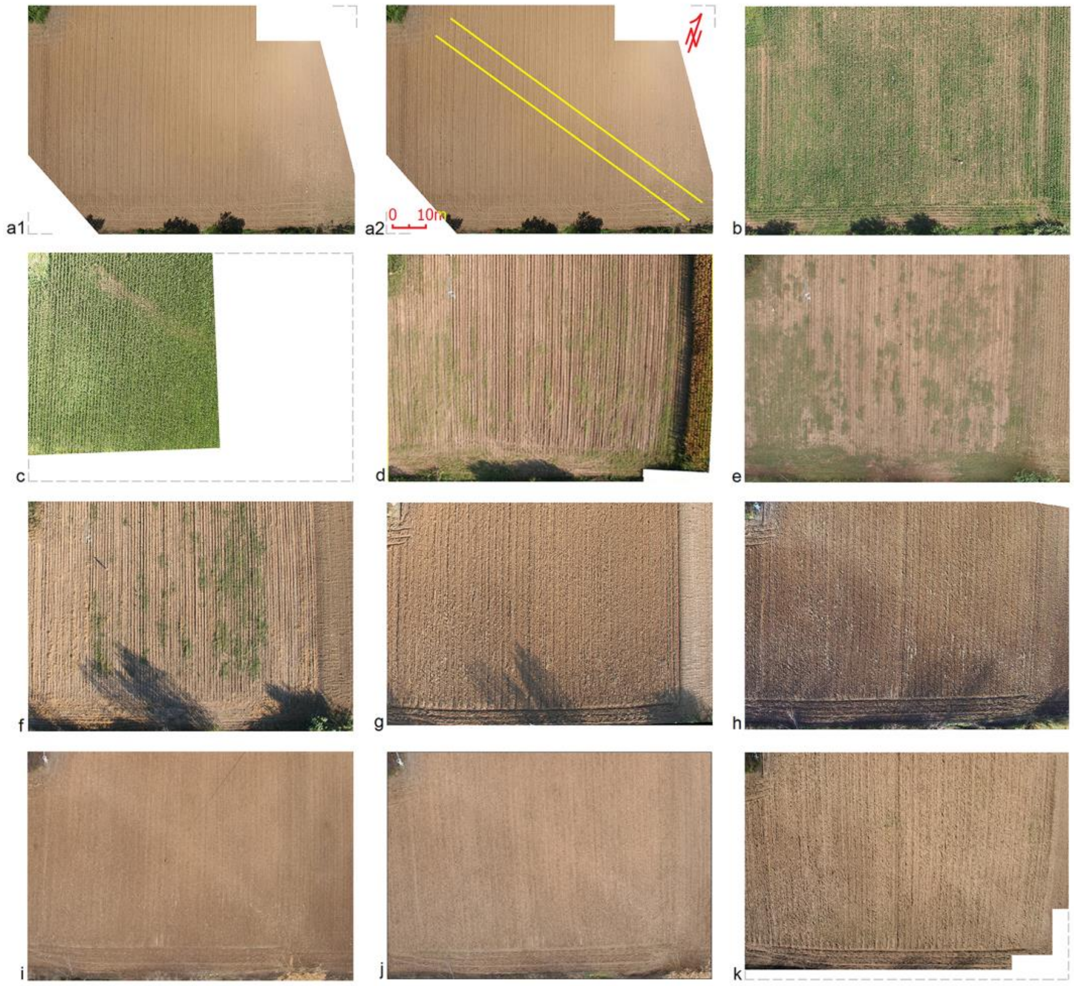


**Figure 14. a1: image acquisition 20/04/2012, a2: yellow line is the course of Via Egnatia, b: image acquisition on 01/06/2012, c: 01/07/2012, d: 12/08/2012, e: 22/09/2012, f: 21/10/2012, g: 17/11/2012, h: 23/12/2012, i: 20/01/2013, j: 23/02/2013 and k: 23/03/2013.**

From the evaluation results (Table 5), and as it can be seen in figure 2 and tables 1, 4, at the beginning of the period A the soil mark of the buried ancient Via Egnatia in position 2 was absent, because the height of the corn was too low (5 cm). According to Lerici (1963) and Riley (1987), the observation of marks of monuments at depths of 2.0-2.4 m for coarse-grained soil, and at depths of 0.5-1.0 m for fine-grained soil is possible under certain conditions. Consequently, the mark cannot be observed, perhaps because, in position 2, the fine-grained soil (as in position 1) and the depth of the Via Egnatia is at 1.6 m. Between the periods A and B the corn had a height of 100 cm, but the depth of the monument prevented the appearance of soil and crop mark. At the beginning of the period B the corn was at its maximum height (200 cm). The age of maturity had not started and, despite the greater depth of the monument, the intense observation of the crop mark was possible. The time, weather and climatic conditions were characterized as ideal for the observation of the crop marks. At the end of period B the soil marks could not be observed (in late summer). From early September to late November, as it was the end of the summer season and a period of low-frequency rainfall followed, which is normal for the season, the soil had minimum moisture and thus prevented the appearance of marks. From the middle to the latter part of period C (early November to late January), the soil mark of the buried ancient Via Egnatia in position 2 was almost absent or satisfactory. The beginning of a period of repeated rainfall (slightly higher frequency and intensity than normal), allowed for the appearance of marks for the first time, despite the low temperatures (normal for the season) and the greater depth of the monument. In February, the frequency and intensity of rainfall were not normal for the season, and the soil mark was satisfactory. If the rainfall had been less, perhaps the intensity of the observation would have been greater. In March, the frequency and intensity of rainfall were normal for the season and the soil mark was absent.

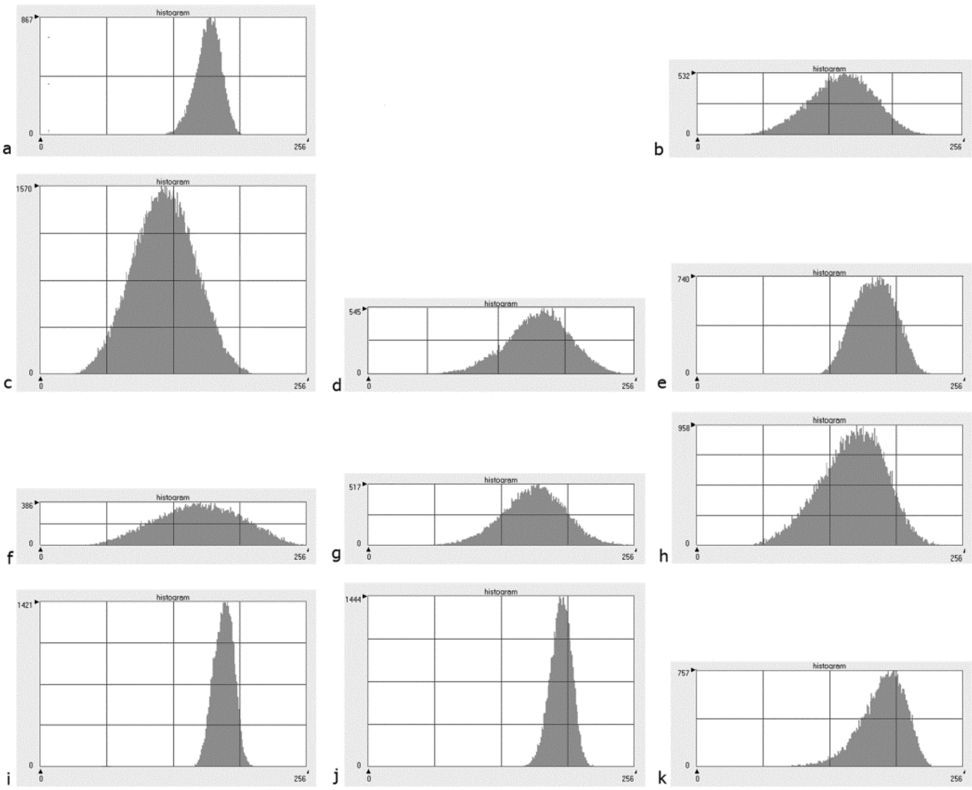


**Figure 15. The histograms of the diachronic images a: 20/04/2012, b: 01/06/2012, c: 01/07/2012, d: 12/08/2012, e: 22/09/2012, f: 21/10/2012, g: 17/11/2012, h: 23/12/2012, i: 20/01/2013, j: 23/02/2013 and k: 23/03/2013, of position 2**

Therefore, the conclusions drawn from Table 5 are:

- It is confirmed that the second (period B) Theoretically Best Period for Marks Detection (TBPMD) provides satisfactory results regarding the intensity of marks.
- The achieved results allow a further reduction of the second TBPMD, i.e. from late June to late July.
- For the crop marks (cultured corn) of parts in Via Egnatia, or of similar buried monuments (morphological/typological), which have not been detected so far in the plain of Philippi and are located at a depth of 1.6 m, the chances detected in new image acquisitions within the above time periods are significantly increased, provided that the weather and climatic conditions are normal for the season.

## 4. CONCLUSIONS

The paper proposes a documentation methodology for the periods in which the marks appear in the study area that is based on systematic, detailed observations of the change in marks of the known buried archaeological structures. More specifically, 22 diachronic images of high spatial resolution were captured (with an image acquisitions system) for a period of one year, under fully known climatic-meteorological conditions, type of soil, crop and depth of the buried monument.

The results of the study are encouraging; it documents the best time for marks detection (in fine-grained soil and cultured corn), and the initial time range is reduced in half. More specifically, the first best period for mark detection is from mid to late April, the second from late June to late July, and the third from mid-December to late January.

The research team will obtain new aerial photographs and satellite images for the entire study area, not only for the detection of new unknown buried structures, but also for the diachronic control and study of the changes (in form, shape, and intensity of observation) of the known marks.

## ACKNOWLEDGEMENTS

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