Uncertainties in spatial modelling of the cultural environment

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Introduction

The quality of spatial data depends on many elements and may affect subsequent processing steps strongly. We can distinguish two groups of errors (Burrough and McDonnell 1998): measurement (inherent) and processing error (spatial analyses and modelling). The errors can be evaluated by statistical methods or by other means. The measurement errors are split to random, systematic and gross. Although the random measurement errors of spatial data are mainly considered to be normally distributed, their character often contains admixtures of poorly explained properties and other uncertainties that came from difficulties in separation between particular types of errors. Error distributions that can be explained with stochastic rules can be modelled by Monte Carlo simulations.

Analyses and modelling of the cultural landscapes could be a high level uncertain process if we don't understand the nature of data well, and especially if there is not enough metadata available. Different kind of spatial analyses require various aspects of knowledge of the data sets and their properties. This paper provides empirical analysis of the effect of data uncertainty that influence particular modelling tasks (visibility, path modelling, catchment, analysis, etc.).

In the paper four approaches to uncertainty analyses and modelling of cultural landscapes in environmental archaeology are exposed: (1) analyses of the Bronze Age settlements and influence of the sea level changes on the analyses of cultural landscape; (2) analyses of the ancient paths – communications between settlements; (3) analyses of the visibility from the significant points; (4) analyses of the social and economical landscape of Iron Age hillforts in the Leithagebirge. The case study areas are situated in Croatia (Central Dalmatia), Slovenia (Dolenjska), Mexico (Yucatan, Campeche) and Austria (Lower Austria and Burgenland).

Problem 1: Information on sea level – Central Dalmatia, Croatia

The estimation and simulation of the sea-level regarding present situation for the selected historical periods: Upper Palaeolithic, Neolithic, Bronze Age, and for Roman Age, was performed. The main objective of the unpublished paper (PODOBNIKAR et al. 2003) was to discuss sea-level data for the Eastern Adriatic coast, Central Dalmatia, including its uncertainty and deviations, for the last 15,000 years. The paper focused on modelling the average sea-level of the Adriatic basin in order to recognize if and how its dynamics could alter the human activity areas from the Neolithic, through the Bronze and Iron Ages, till the Roman Age. The aim was twofold: to observe settlement patterns over their likely past sea-level shape, and to verify regularity of spatial analyses and re-evaluate corresponding hypotheses regarding data sources that correspond to recent environment and water source data.

Many spatial analyses have been performed and interesting results were obtained for the area of the Central Dalmatia. The analysis and the results were promising; nevertheless these spatial analyses were all based on the present coastline. The idea was that the coastline changes might be an important factor of reliability of the archaeological spatial analysis. For modelling of the sea-level changes, a digital terrain model (DTM) and a model of the sea bottom surface (bathymetrical DTM) were integrated into one digital surface model. The global sea-level model indicates 14 m of difference between the Neolithic (–6 m) and Bronze Age (+8 m on average). According to the nowadays sea-level, we can note variations from 1 and up to 8 m. With such amplitudes, we can be expecting substantial landscape modifications, which can alter our perception of territorial dynamics during past times. The result of the sea level change on the coast line can be according to Rohling et al. (1998) inspected in Fig. 1.

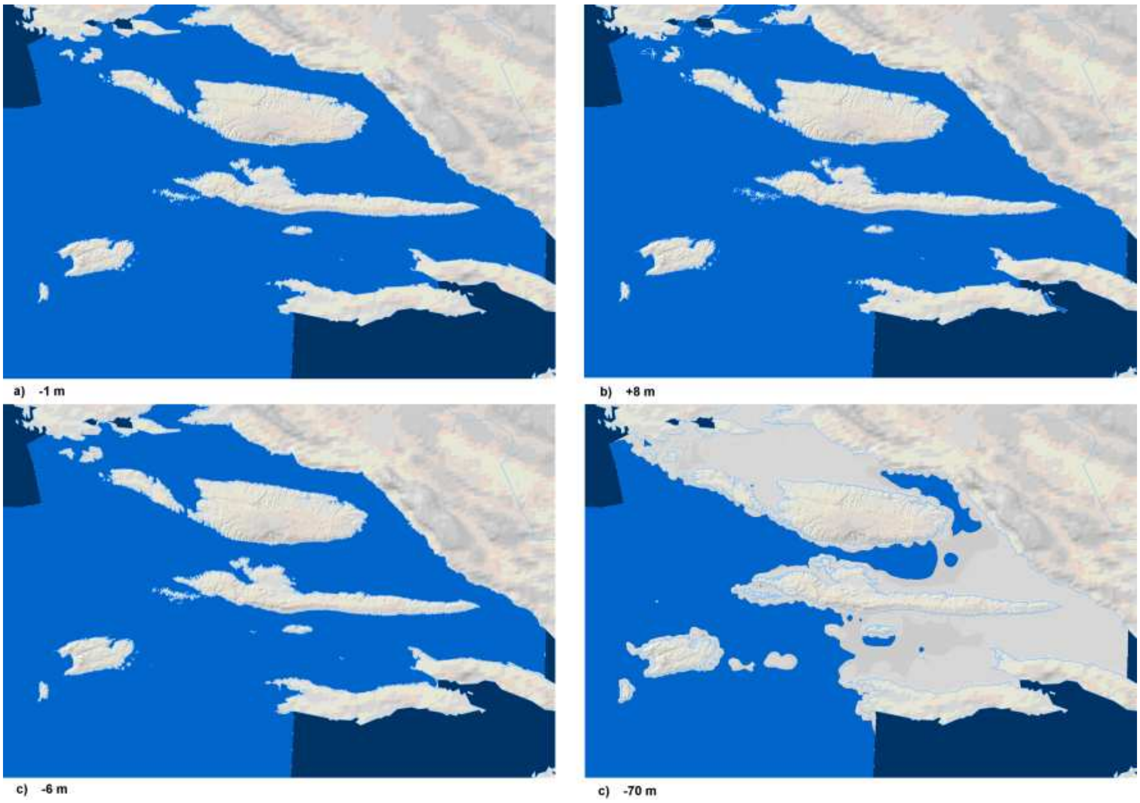


Fig. 1 - Coastline variation of simulated models of palaeolandscapes for the Roman age, –1 m (a), Bronze Age. +8 m (b), Neolithic, –6 m (c) and Palaeolithic, –70 m (d).

Under these conditions, we can assume that sea-level has a significant impact on the settlement organisation. This analysis was performed within a geographical information system (GIS). The results verified that the settlement pattern was not noticeably affected by sea-level changes in the last 10,000 years due to the fact that most of the islands had rather steep slopes which resulted in a low coastline variation. However, in the case of the Starigrad plain on the island of Hvar (Fig. 2), with a large plain with a low elevation in respect to the sea, a significant impact of sea-level change could be observed.

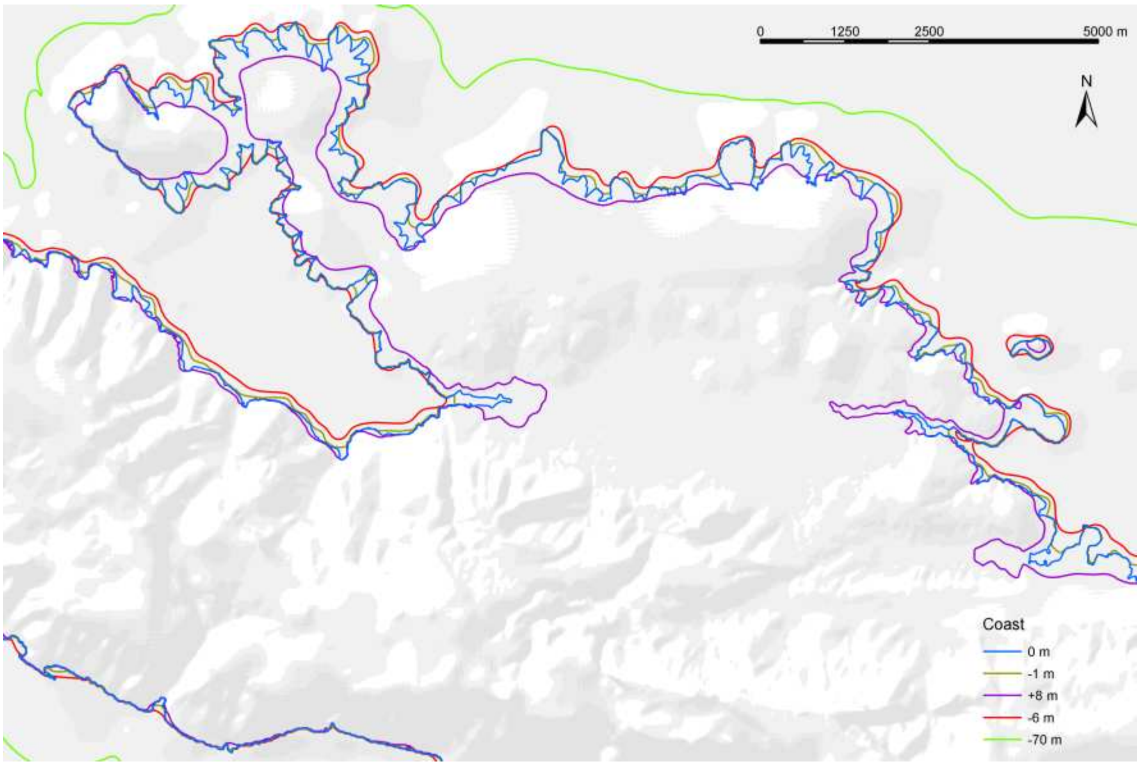


Fig. 2 - Coast line variation of different periods in the central part of the island of Hvar.

Though, before the publishing of the paper it turned out that the estimated sea-levels based on the global model was not valid within the project area. This error in the model pulled down all of the all nice archaeological theory that could be constructed from the results. The problem was that during further investigations no archaeological studies were found that proved for the Bronze Age a sea-level of 8 m higher than present Mediterranean coastline. It is confirmed by historians and archaeologists that in the east Mediterranean the recent coastline had effectively been reached by the Late Neolithic (with minor, or just occasionally dramatic, local variations (MITROVICA 2003)). The main problem in the failure of the study seemed to be that a global model of the sea-level changes was applied that deviates significantly from the local one (Adriatic Sea).

Problem 2: The influence of DTM quality on path simulation – Dolenjska, Slovenia

Within this study the simulation of possible courses of the ancient paths regarding environmental characteristics were performed. The simulation enables the variation of different parameters, for calculating the path between selected points. The algorithms were applied with spatial analysis in GIS. On the basis of similarities of archaeological remains, we assume strong contacts and exchanges between the settled centres. Our assumptions of the optimal paths modelling were the following (PODOBNIKAR et al. 2004): (1) predominantly hilly terrain as the most important factor, (2) climate regime and other environmental conditions such as marshy soil, size of the rivers, vegetation, geology could also be of importance; however, we suggest that these conditions have not been changed drastically to the present day, (3) evidence of boats for river movement and wagons are not available, so we assume the settlers used to walk between the chosen settlements within the landscape, and (4) the impact of cultural and socio-economic factors on the decision making process.

The chosen study area was the central-southern region of Slovenia, named Dolenjska, which is limited by natural boundaries of the river Krka on the south-west side and the river Sava on the north-east (Fig. 1). 14 Iron Age settlements from a total of 38 documented in this area were selected and the presence of 18 paths that run between them were studied. The paths' simulation was performed just based on the DTM which seemed to be the most important factor. All of the algorithms base on least-accumulative-cost distance over a cost surface. In order to evaluate the results nine sets of cost surface parameters within the simulation were selected (PODOBNIKAR et al. 2004). Some results of these simulations can be inspected in Fig. 3.

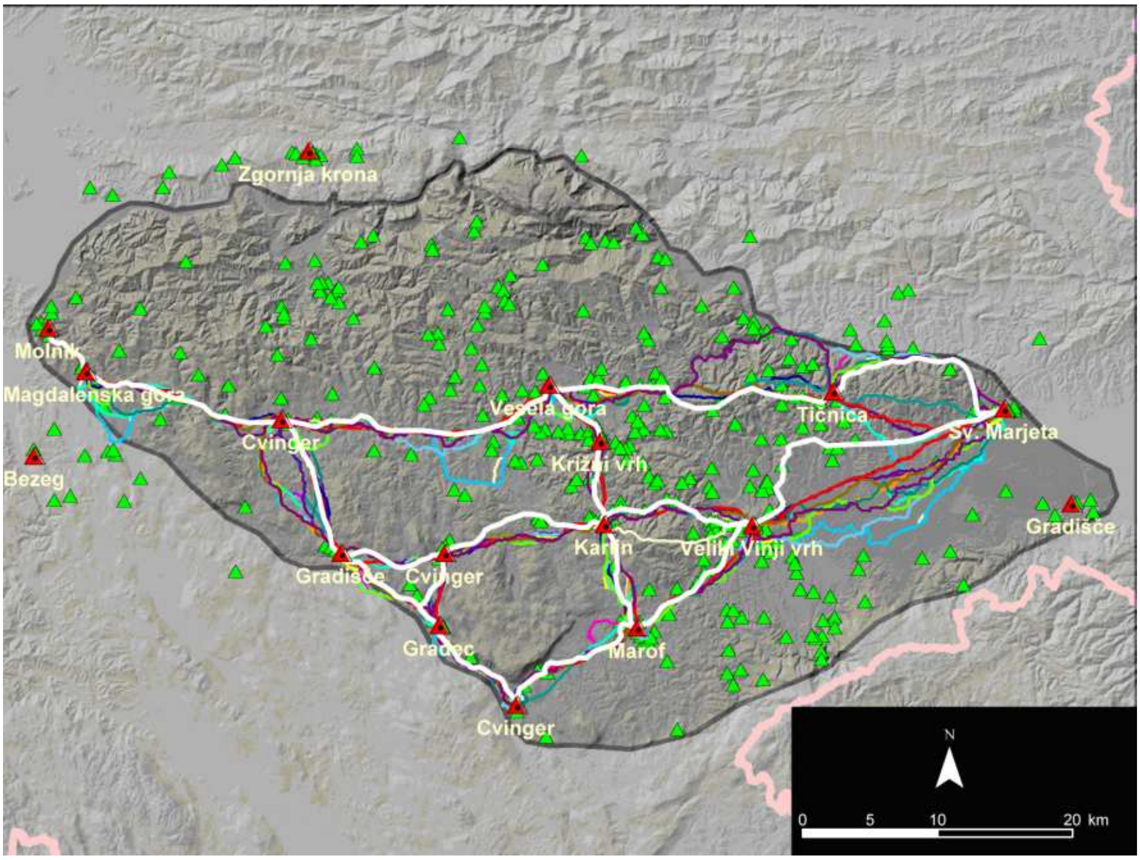


Fig. 3 - Simulation of ancient paths using nine different cost surface models. On the flat areas, the possible courses are more dispersed. The white line illustrates paths that were determined by the subjective knowledge of archaeological experts.

Analysing the results it could be recognised that simulated paths on the hilly areas are less dispersed and denser than on less hilly areas as such areas offer fewer possibilities for economical transport. On less hilly areas, other factors are more important than terrain. The archaeologist can subjectively interpret which simulated algorithm or which paths are more relevant. On the base of the presented simulation some segments of ancient paths were founded by archaeologists soon after implementation of the algorithm! This shows the importance of parameter variation. The visualisation of all results within one figure allows inspecting possible areas of uncertainties in the simulation results.

However, it has to be considered that for a more reliable study the significance of further factors influencing the run of the paths might be necessary. The importance of the factors fluctuates in respect to the different geomorphology of the area. Within this study we could show with the empirical tests that simulations allow to detect the paths quite reliable. Some of the significant influence factors are: (1) stability of the starting point; in some cases small changes can lead to different path, (2) selection of the appropriate algorithm for path calculating, (3) selection appropriate cost surface weights in the algorithm and other constrains (e.g. what kind of path is it, what kind of transport was there), (4) the path from one point of the other is newer the same to the reverse path direction (anisotropic), (5) gross errors on the DTM can play an important role, (6) various quality of DTMs (considered without of gross errors) and resolution can lead to differently simulated paths (cf. Fig. 4).

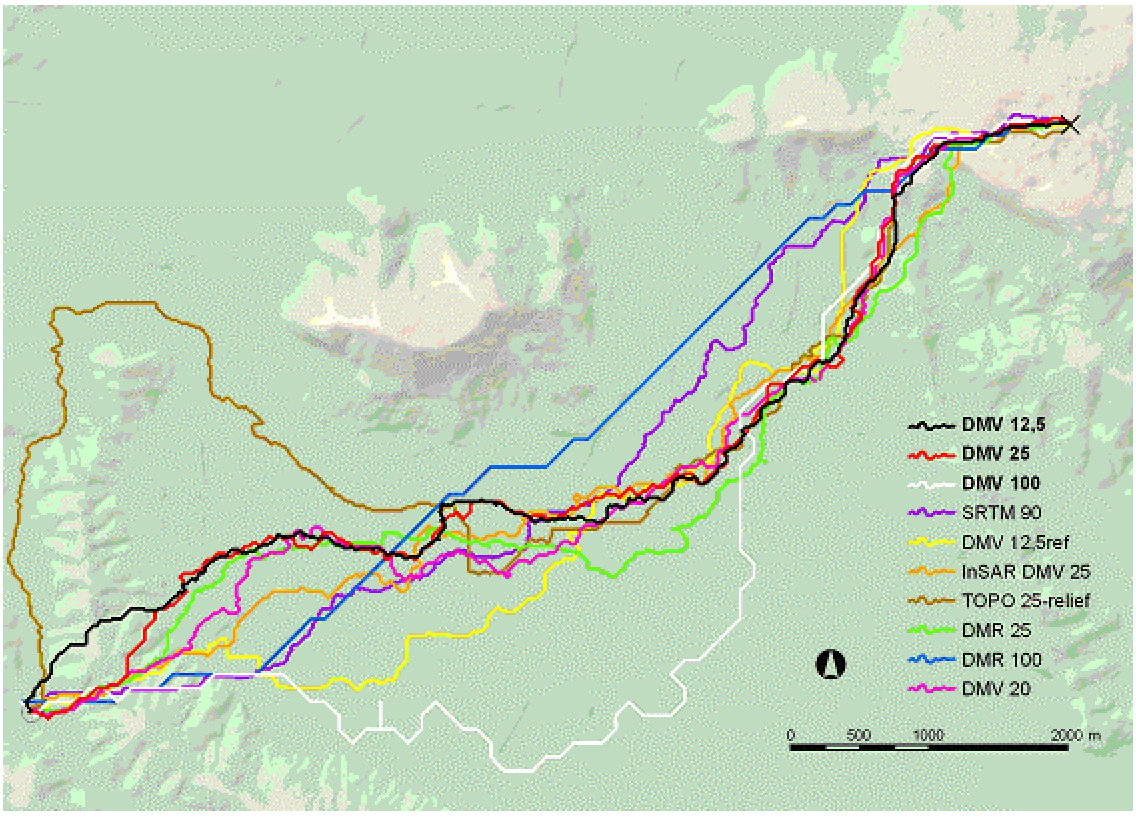


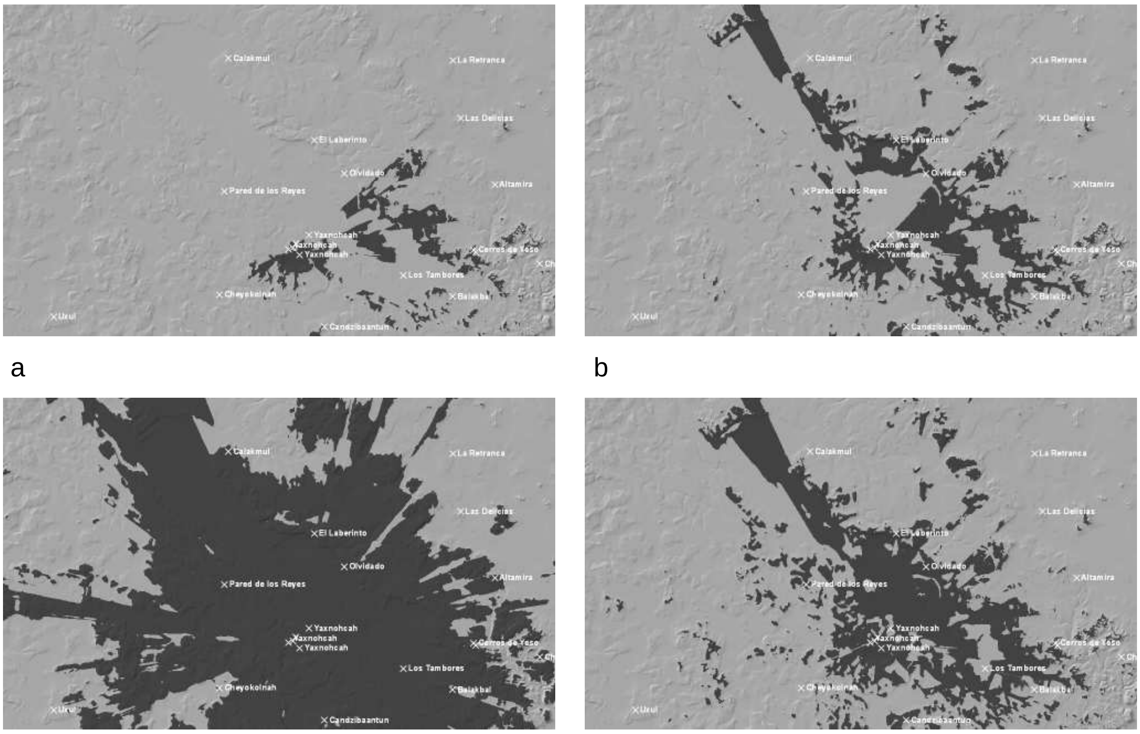
Fig. 4 - Simulated paths determined from DTMs with different quality using the same path determination algorithm and parameters.

Problem 3: Influence of height uncertainty of pyramids and vegetation cover on visibility studies – Yucatan, Mexico

The visibility studies of the archaeological sites can contribute to the understanding of several questions: Is visibility from archaeological sites connected with the landscape perception? Are natural aspects of site locations significantly different from other (average or randomly selected) areas? How did the visibility and inter-visibility influence the location choices? Are there any significant spatial patterns? Was it possible to communicate between the neighbouring centres or to control others from the tops of the sites? How much of the area was controlled from the sites? Are the answers to those questions clear and significant?

Our primary assumption was that visibility played an important role in settlement patterning in the Maya Lowlands central parts of the Yucatan Peninsula in Mexico (PODOBNIKAR and ŠPRAJC 2007). Since the area has so far been practically unexplored, the final results represented a significant contribution to the understanding of the Maya culture in central lowlands of the Yucatan peninsula. Visibility studies have been performed and intervisibility between centres has been determined. Viewsheds from all of the sites, with different offsets of heights for observation and observed (target) points, helped us to understand the terrain characteristics, possible visual communications between different centres, reasons for the chosen centres locations, etc. We have proven that positions of the centres chosen by the Maya lie significantly in areas that are more visible than the average (random) study area.

The visibility analysis requires a high quality DTM, information about heights of the buildings – mostly pyramids (53 from 40 major, medium and minor centres) that are used for observations – artificial outlooks and information about vegetation cover. Visibility maps from all 53 structures were calculated. Fig. 5 presents the results of these simulations using different parameters for Structure B-3 of Yaxnohcah. Fig. 5a shows visibility from the ground with offsets of 2 m (2/2 m – for observation/target or from/to points) applied to the observation and target point; it reveals that the site's visibility potential was rather poor before the pyramid was built. Fig. 5b with offsets 10/2 m presents visibility from small pyramids or trees about 10 m high; we can see that large areas to the NW have become visible. Picture c shows an extreme case with offsets of 30/30 m, when the observer stays on the top of tree and observes the tops of other trees. The examples illustrated in Fig. b and c are useful for a better understanding of the natural terrain characteristics regarding chosen observer points and data quality. They can also help us to understand the why the founders of the particular sites have chosen their positions and what they might have possibly seen from the trees before they built the settlements. Fig. 5d, shows a situation after the pyramid with a height of 20 m was built and furthermore assumes that the vegetation was cut down in order to produce viewsheds that are as realistic as possible.



a b

c d

Fig. 5 - Viewsheds from Yaxnohcah Structure B-3 with different offsets, showing the visibility potential of the site. Offsets (from/to) are 2/2 m (a), 10/2 m (b), 30/30 m (c) and real heights of all selected pyramids (20 m for Yaxnohcah Structure B-3) with offset 2/2 m (d).

Visibility analysis helps to understand the importance of visual communication. This seemed to be very important for the Maya settlements on Yucatan peninsula. The basic data were the DTM and heights of the most dominant pyramids. The most unknown variable is vegetation. The visibility was simulated with or without vegetation from the areas of pyramids or their tops. The study shows on one hand a quite high sensitivity to possible errors on DTM or heights of pyramids for some sites and on the other hand it describes the intervisibility between some pyramids that can not be tested in reality, due to of dense vegetation that cover the selected area nowadays. Namely it seems that some pyramids are positioned on special positions that allowed visual communication, as it was shown by different analyses. However, it is impossible to validate these results in field.

Problem 4: Improved DTM quality for archaeological prospection in forested areas by advanced geo-referencing and classification of Airborne Laser Scanner Data – Lower Austria, Burgenland, Austria

Within the research project "LiDAR supported archaeological prospection of woodland" (Austrian science found, P18674-G02) the ability of recognition and measurement of archaeological sites with airborne laser scanning (ALS, often referred to LIDAR, cf. WEHR and LOHR 1999) in forested areas is investigated. During the first phase of the project, a test scan covering two 4 km² areas was performed. Its main purpose was to access the potential of the technique for archaeological reconnaissance in forests. In order to recognise the low round barrows (5 m – 15 m in diameter with a height of 0.2 m to 2 m) which are present in the test area a very dense and accurate sampling of the surface is essential. Furthermore, the high point density increases the probability that some of the emitted pulses can penetrate the vegetation and that an echo from the terrain can be observed. Additionally, in order to allow a detailed analysis and an advanced determination of the terrain points the newest generation of ALS sensors that allow full-waveform registration (very dense sampling of the whole received echo signal) was chosen. The resulting ALS data set had a point density of approx. 6-10 points per m², which seamed to be a good basis for the determination of a DTM for the archaeological analysis (DONEUS and BRIESE 2006).

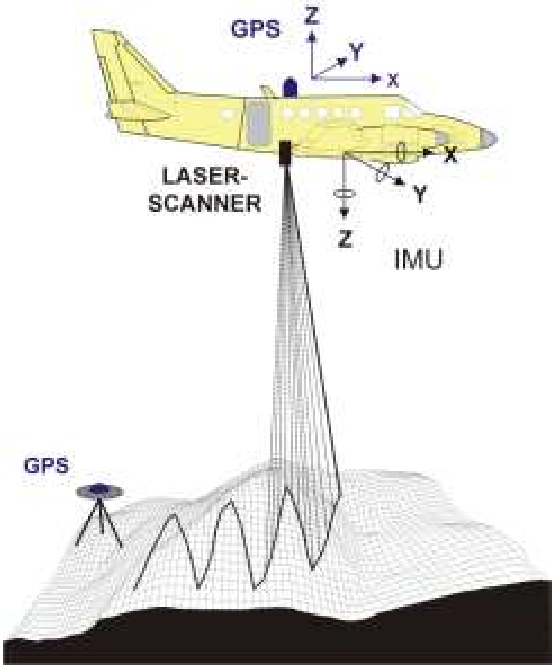


Fig. 6 - Airborne laser scanning. Data acquisition principle.

However, next to the dense sampling an adequate geo-referencing of the data with a high absolute and especially relative accuracy is essential. For the georeferencing of the ALS data a position and orientation system, that typically consists of a global navigation satellite system (GNSS, e.g. GPS) and an inertial measurement unit (IMU), is necessary (cf. Fig. 6). Based on these systems the acquired ALS data, which typically covers the area of interest with overlapping flight strips, can be transformed into one common coordinate system. Though, due to limitations of the sensors differences between two overlapping strips can be observed (see Fig. 7). In order to reduce these differences after the process of direct geo-referencing the data a strip adjustment is essential (KAGER 2004). Within this process surface areas (so-called tie elements) between the overlapping strips are used to minimise the differences between all the strips within an adjustment procedure. The improved result of the process can be inspected in Fig. 7.

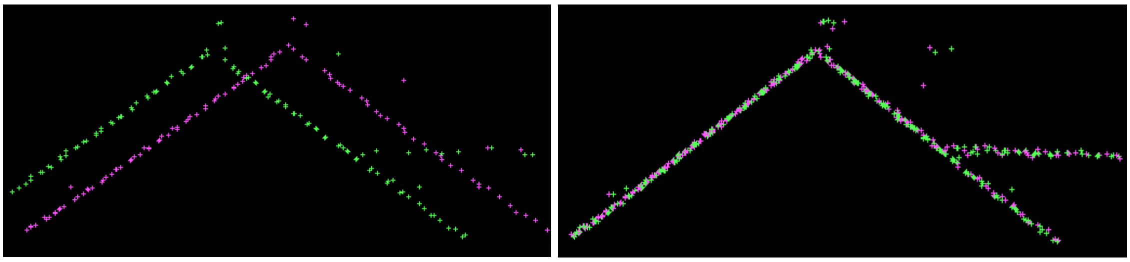


Fig. 7 - Differences of two ALS strips before (left) and after (right) fine geo-referencing of the data (points of the first strip: green; points of the second strip: magenta). KAGER 2004.

After this process the resulting point cloud of all strips has a very high relative and even absolute accuracy if any pass elements are available. Typically the planar accuracy of the points is below 30 cm to 50 cm and the height accuracy is better than 10 cm.. Based on these points a classification of the points into terrain and off-terrain points can be performed. This process can be improved – especially in areas with low vegetation – by the supplementary analysis of the additional information – echo with and amplitude derived from the full-waveform information. The resulting point cloud allows a very accurate determination of a DTM which is a good basis for the subsequent archaeological interpretation of the area. In Fig. 8 the Iron Age hillfort can be clearly inspected. Within the test project a significant improvement due to the advanced geo-referencing of the ALS data could be observed. Artefacts that were introduced in the overlapping areas could be reduced significantly and the classification of the points into terrain and off-terrain points could be done more reliably. This allowed an advanced representation of present archaeological features.

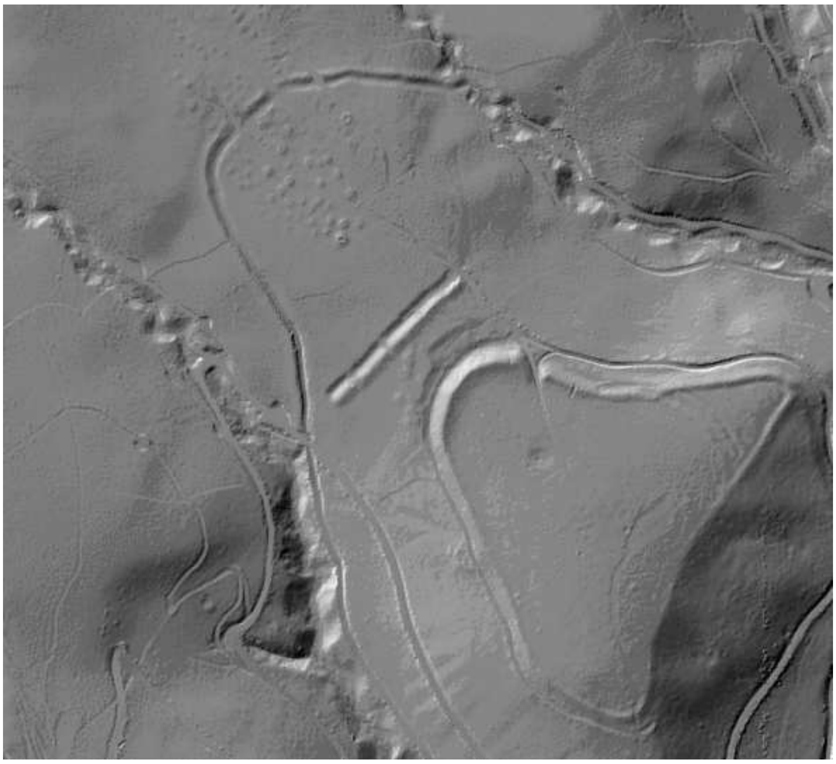


Fig. 8 - Shading of the resulting digital terrain model of an Iron Age hillfort in the Leitha mountain range after the process of fine geo-referencing and advanced classification using the additional full-waveform information.

Conclusion

In the study, four different exampled were explained and possible problems of the results were analysed. (1) The analysis of the Bronze Age settlements and their cultural landscape show that just slightly wrong information on a sea level changes can produce unpredictable results on spatial analysis and at the same time deny all the reliable look hypotheses behind. (2, 3) Analysis of the ancient paths or visual communications introduced the examples where the results could be unexpected and they therefore need additional verifying. In our case the simulation of different possible parameters was tested. The results shows that in the some cases just slightly different coordinates (points) that present locations of starting and target points for paths or points for observation can introduce completely different solutions. Additional problem can be uncertain quality of the used DTMs. One of the reliable solutions of such problem could be in (Monte Carlo) simulations of different parameters and finding the most possible result(s) (4) The last example plays with interpretation of ancient hillforts and barrows using or producing a high quality DTM. Due to filtering-out of some artefacts some barrows could be eliminated or opposite, false (no existent barrows) can be interpreted. The solution lies in better algorithms for DTM production that should be adjusted to particular problems (determined with field work or other data and tools).

The presented examples show an importance of understanding the data that are used for the certain application and algorithms behind the modelling. To enhance the understandability, the problems and data should be carefully studied. Not perceived gross or systematic error or not assessed random error may cause unexpected and even wrong results of the particular study. For the spatial studies is always very important understanding of the problem and understanding the procedures and results. Decision maker should be then able to do a relevant interpretation of his work.

References

Burrough, P. A., McDonnell, R. A. 1998. Principles of Geographical Systems Information Systems : Spatial Information Systems and Geostatistics. Oxford University Press.

Doneus, M., Briese, C. 2006. Digital terrain modelling for archaeological interpretation within forested areas using full-waveform laserscanning. In: M. Ioannides, Arnold, F. Niccolucci and K. Mania (Editors), The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2006).

Kager, H. 2004. Discrepancies between overlapping laser scanning strips - simultaneous fitting of aerial laser scanner strips. In: International Archives of Photogrammetry and Remote Sensing, XXXV, B/1, Istanbul, Turkey, pp. 555–560.

Mitrovica J. X. 2003. Recent controversies in predicting post-glacial sea-level change. Quaternary Science Reviews 22, Elsevier Science Ltd., pp. 127-133.

Podobnikar, T., Nuninger, L., Gaffney, V., Stančič, Z. 2003. Past human activities concerning palaeo-environment in the Central Adriatic Islands, 23 pp. (unpublished paper).

Podobnikar, T., Šprajc, I. 2007. Spatial analyses and Maya cultural landscape. In: Las Tecnologias de la informacion y las Comunicaciones y su contribucion a un Mundo Mejor. La Habana.

Podobnikar, T, Tecco Hvala, S, Dular, J. 2004. Iterative approach to ancient paths modelling in the Iron Age study of the Dolenjska region (Slovenia). In: Fischer Ausserer, K (ed.). [Enter the past] : the e-way into the four dimensions of cultural heritage : proceedings of the 30th conference, (BAR international series, 1227). Oxford: Archaeopress, pp. 254-257.

Rohling E. J., Fenton M., Jorissen F. J., Bertrand P., Ganssen G. and Caulet J. P. 1998. Magnitudes of sea-level lowstands of the past 500,000 years. Nature Macmillian Publishers Ltd., Nature, vol. 394, pp. 162-165.

Wehr, A., Lohr, U. 1999. Airborne laser scanning - an introduction and overview. ISPRS Journal of Photogrammetry & Remote Sensing, 54.

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