Detection of Ancient Settlement Mounds: Archaeological Survey Based on the SRTM Terrain Model

B.H. Menze, J.A. Ur, and A.G. Sherratt

Abstract

*In the present study we demonstrate the value of the SRTM three arcsecond terrain model for a virtual survey of archaeological sites: the detection and mapping of ancient settlement mounds in the Near East. These so-called "tells" are the result of millennia of occupation within the period from 8000–1000 BC, and form visible landmarks of the world's first farming and urban communities. The SRTM model provides for the first time an opportunity to scan areas not yet surveyed archaeologically on a supra-regional scale and to pinpoint probable tell sites. In order to map these historic monuments for the purpose of settlement-study and conservation, we develop a machine learning classifier which identifies probable tell sites from the terrain model. In a test, point-like elevations of a characteristic tell shape, standing out for more than 5 to 6 m in the DEM were successfully detected (85/133 tells). False positives (327/(600*1200) pixels) were primarily due to natural elevations, resembling tells in height and size.*

Introduction

The study of "tells" is a fundamental category of archaeological research. Tells are settlement-mounds which are found in the Near and Middle East, in an arc from the Balkans to north-west India and represent prehistoric and early historic villages and towns. These were typically occupied for long periods of time, often several millennia, during which the mud-based building technique caused building debris to accumulate, and build up into a substantial mound, giving advantages of visibility and protection. These prominent landmarks of early human activity began to appear when the spread of farming in the Neolithic period (8000 to 6000 B.C.) gave rise to permanent villages, and such sites continued through to the Bronze Age (3000 to 1000 B.C.), when some grew to the size of major urban centres. Although one or two are still inhabited, most of the mounds were abandoned two to three thousand years ago, and modern settlements exist on flat land nearby. These artificial mounds thus represent the remains of the earliest settlement systems, and a study of their spatial occurrence can reveal insights into the emergence, development, and organization of the first complex human societies.

A comprehensive and accurate listing of these sites is thus a research priority, and has hitherto been achieved (for restricted areas) by survey on the ground. In consequence, there is no overall picture of the distribution and relative density of these features, and the known pattern is largely a reflection of the differential intensity of investigation. The locations of known sites are not well recorded, because of the unavailability of large-scale maps in these areas. Remarkably therefore, after more than 150 years of archaeological research, information about the locations even of major sites is notoriously imprecise, while most smaller mounds never made their way into the record. As a consequence, current compilations of published site positions are only available on coarse grids and contain no more than a subset of potential sites (Sherratt, 2004). This is especially regrettable because the surviving population of ancient settlement mounds is increasingly under threat: expansion of modern settlements, road building, and the intensification of agricultural land-use has brought an unprecedented rate of destruction to these historical monuments. Not only are these sites of academic interest in the study of ancient settlement patterns, but they are themselves valuable aspects of the cultural heritage. At the present time, they are probably disappearing faster than they are being recorded, and this is undoubtedly true of the smaller examples.

This unsatisfactory situation was transformed in 2004 by the publication of SRTM data. For the first time it became possible to observe topographic phenomena at the scale of tell settlements, which as artificial mounds stand out as well-defined anomalies from the flat lowland landscapes in which they are typically situated. The aim of the present work is to develop and assess a (semi-) automatic tell detection strategy, which is based on SRTM digital elevation models and will allow a virtual survey of ancient settlement mounds over wide geographic areas, under objective search criteria, and at low operational costs. This is already beginning to provide a representative list of sites for detailed assessment and ground truthing.

In the following, we will at first discuss possible approaches in the remote sensing of these archaeological sites. Then, a machine-learning algorithm is proposed, which is trained and applied to the SRTM data of a test region. This algorithm is able to identify the typical conical tell pattern

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of a settlement mound within the natural topographic variation, and will be used in a (semi-) automated survey for tell sites. The detection accuracy will be discussed in relation to of the size and height of the tell mounds, as derived from SRTM data and other sources of information.

Remote Sensing of Settlement Mounds

From a simple physical point of view, tells are features of 5 to 50 m height, 50 to 500 m diameter, and usually of conical shape. Also, they primarily consist of loam and mud-based materials (Figure 5). Both features might be used in the identification of tell sites: multispectral imagery, e.g., from LANDSAT, is a standard tool in the classification of soil types and ground cover. It is potentially helpful to identify the often un-vegetated and eroding tell sites. Digital elevation models reveal shape information, and their potential usefulness in the search for tells was identified by one of the authors shortly after the data were released (Sherratt, 2004). Data for both approaches are available with high spatial resolution and wide coverage. Unfortunately, the spectral signature of known tell sites has so far proved to be too unspecific to serve as a diagnostic characteristic in an automated classification. Thus, the detection of tell sites falls back on an optimal processing of the DEM data, with the supplementary use of high-resolution satellite imagery and other georeferenced information.

The interesting regions of the Near East are covered by a number of digital terrain models, although most of them (e.g., GTOPO30, GLOBE) do not satisfy the required spatial resolution. In addition to the (3 arcseconds) SRTM data, only the ASTER-derived DEM has the potential to map elevations of tell size. However, a qualitative comparison of these two models already demonstrates the major disadvantage of the latter (Figures 2 through 4). In areas with high gradients (mountain walls and ridges, rivers banks, but also some of the major tell sites), ASTER data do reveal unique details at its maximum (30 m) resolution. Unfortunately, artifacts in size and shape similar to a settlement mound characterize the ASTER DEM in the studied area (Figure 2; compare with topographic map in Figure 4). Comparison with Landsat images suggests a dependence of this effect on the type of agricultural land-use (Figure 3). As the artifacts are primarily a problem in the flat plains (where the tells are expected) a use of this DEM in an automated or even visual search for tell sites is not too promising. As a consequence, the proposed virtual survey for ancient settlement mounds is primarily based on a processing of the SRTM model.

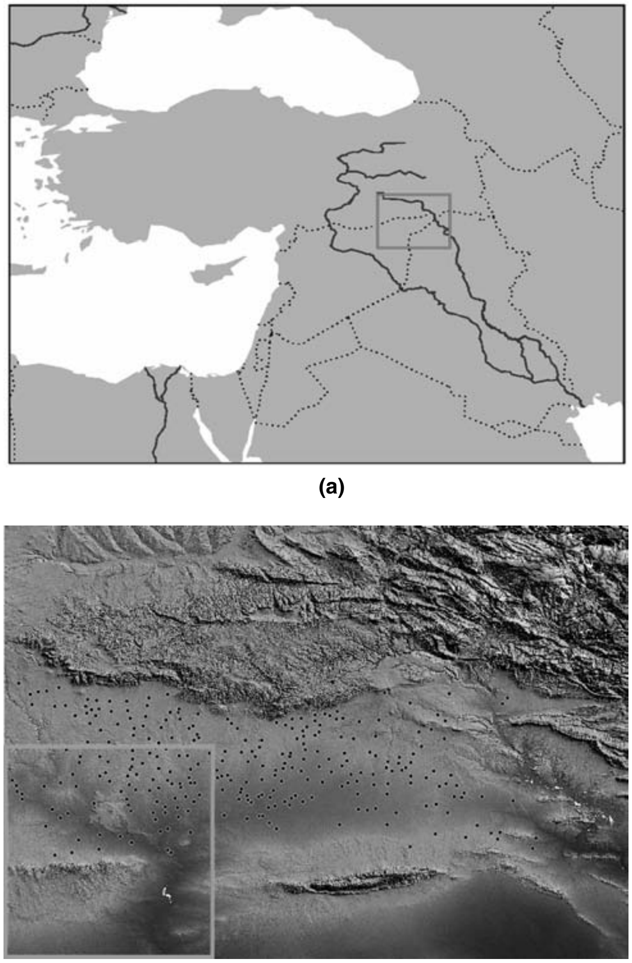
Surveying the DEM

Data

The data used in this study are from a test area in the north of Mesopotamia (Figure 1). The upper Khabur catchment has a long settlement history, and saw the major expansion of nucleated settlements in the fourth millennium B.C. It is one of the regions where archaeological settlement surveys were developed and which is still a focus of current research (Ur, 2004). The basin, which lies mainly in Syria and in adjacent parts of Turkey and Iraq (Figure 1) measures roughly 320 km from east to west, and 120 km from north to south. It is covered by six SRTM one-degree tiles (36N to 38N; 38E to 41E) at three arcsecond resolution (90 m, Figure 2). DEMs from several ASTER swaths are also available for the region (as obtained from DAAC).

As part of ongoing archaeological investigation of this region, 133 sites with an indication of settlement activity had been identified within tile 36 N, 38 E (Figure 2). The tell sites had been identified from Corona images and several seasons of fieldwork associated with excavation projects (Ur, 2002; Wilkinson, 2002). Photogrammetric maps originally made for land improvements were also available for a small part of test region (photogrammetric survey of the Hasake region; 1:5000 scale copies in Ashmolean Museum, Oxford), and these provided contours at a 1 m interval (Figure 4). The size of these tells ranges from one to 60 ha in area and from less than 5 m to more than 50 m in height (Tell Brak; Figure 5b).

In order to keep this validated data as an independent test set in the comparison between archaeological ground survey and virtual SRTM survey, a second data set was acquired for the training of the classification algorithm. For this purpose the remaining SRTM tiles of the Khabur (Figure 1b) were visually searched for settlement mounds, and, with help of Landsat-ETM+ images and under the guidance of topographic maps (Soviet topographic maps, 1:100 000, U.C. Berkeley map collection), it was possible to identify another set of 184 settlement mounds (Typical evidence for these sites as illustrated in Figure 3.).


(a)

(b)

Figure 1. (a) Map of the region under study. The Khabur basin is in the north of Mesopotamia (Euphrates and Tigris indicated), and (b) digital elevation model of the Khabur basin with settlement mount positions indicated (black dots). Tells of the southwestern SRTM tile (bordered) were confirmed by archaeological survey and serve as test sites.

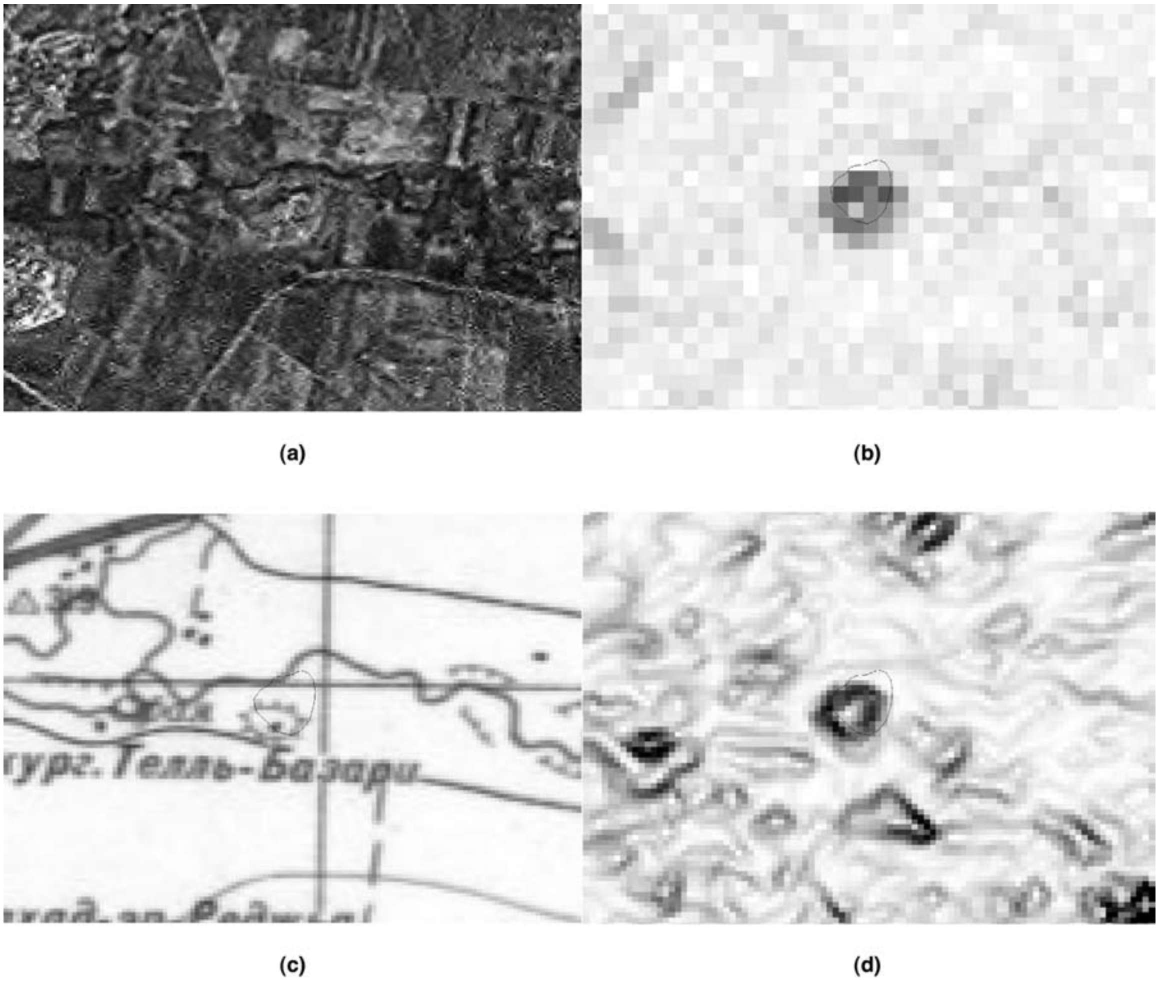


Figure 2. Landsat ETM+ imagery (a) was used to assess the sites detected in the SRTM (b) gradient image. Topographic maps (c) provide (modern) names of the sites and objective *ground truth*. Comparing ASTER DEM (d) and SRTM data, the three times higher resolution of the first reveals detail of the site, which are in line with the Landsat observations. Artifacts in the ASTER model are often indistinguishable from elevations of tell size (compare the high resolution topographic map of Tell el Bazari, Figure 4). Outlined are site extensions as assessed from Corona imagery.

Tell Detection

Within the DEM data, these mounds usually appear as small contrasting spots (Figure 6). Although the geographic region under study is a relatively flat plain, natural variation of the land surface exists on various scales, ranging from slowly varying slopes to steep canyon walls (Figure 1b and Figure 7). This variation is superimposed on the characteristic point-like pattern of the tells. The standard approach for the detection of a known pattern in a varying background signal is a matched filter. Unfortunately, the direct application of such a template matching and the cross-correlation of the DEM with the prototype pattern of a settlement mound results in an unacceptable number of false hits (Figure 7).

An extension of the signal detection to a binary classification problem allows a more specific pattern recognition. In addition to the 184 tell sites, a set of 50,000 positions was randomly sampled to represent the natural *background* variation. For each of these sites, the elevation data of its surroundings (circular regions of 11 pixels with 1 km diameter) was transformed into a vector after a subtraction of the elevation of the central pixel. This resulted in a 80 dimensional parameter vector containing the height differences of the DEM patch relative to the training site in the center.

Then, a set of partial least squares (PLS) filters was learned from the data, following ideas primarily used in face recognition (Belhumeur *et al.*, 1997; Baek and Kim, 2004). The purpose of these linear filters is to allow a fast processing and low-dimensional mapping of the (80 dimensional) tell pattern (Menze *et al.*, 2005a). Finally, a multivariate classifier, learned in a subspace of the PLS projection, provides the desired adaptability of the detection algorithm. In the given application, a Random Forest classifier (Breiman, 2001) operating on an eight dimensional PLS subspace reached a sensitivity of 95.4 percent at a specificity of 98.8 percent in a ten-fold-cross validation of the training error (Figure 8; cross validation over both PLS feature extraction and classification; all computation using open source software and freely available routines (R Development Core Team, 2004)).

Applied to new data, the classification algorithm is able to provide ranked lists of positions with decreasing *settle-*

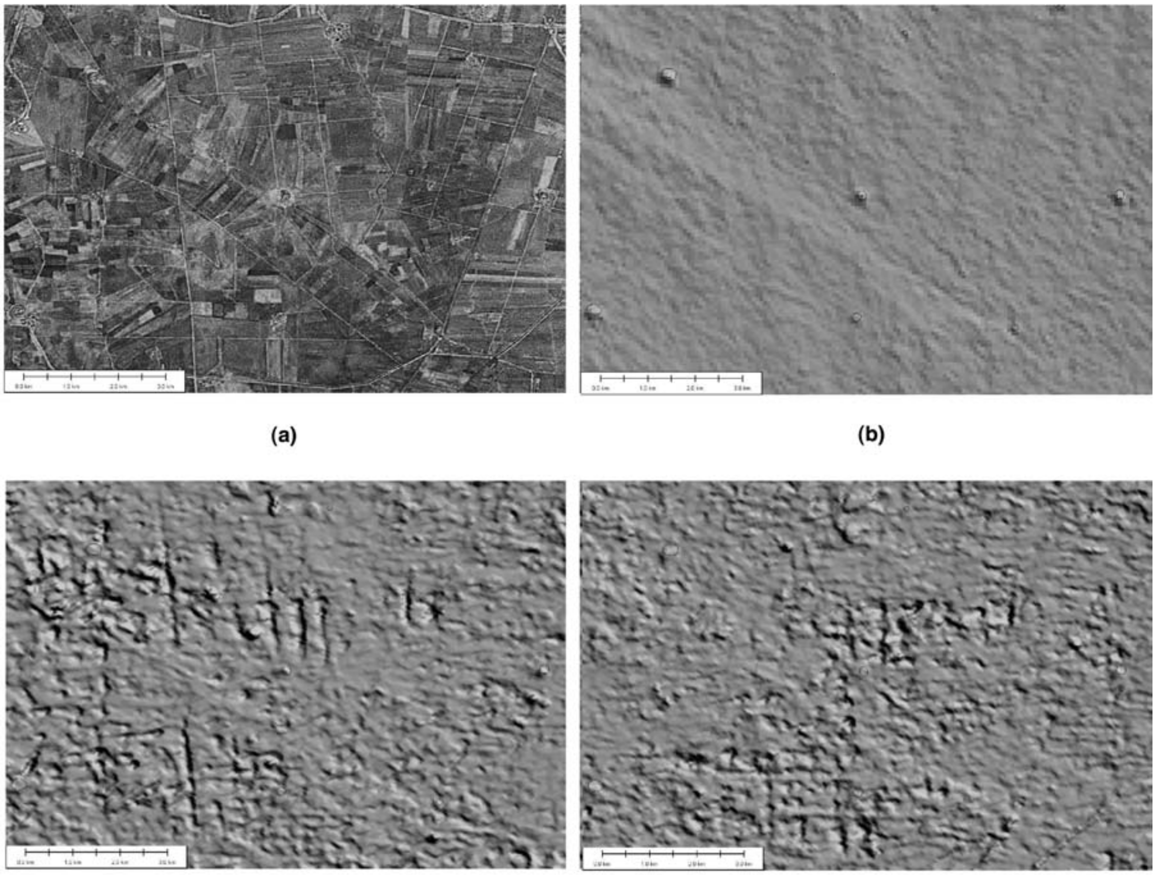

(a) (b) (c) (d)

Figure 3. View onto a central part of the test region. Tells can easily be spotted from the SRTM DEM (b). The Landsat view (a) reveals the close vicinity between modern settlements and ancient settlement mounds. Although several ASTER swaths (c) and (d) are available for the generation of elevation models, they all suffer both from small scale (Figure 2) and extended artifacts, which often correlate with the type of ground cover, such as streets, channels, and even crop fields. Scale bar in the lower left image corner indicates 3 km. The color version is available at the ASPRS Web Site: *www.asprs.org*.


Figure 4. Topographic maps at 1:5000 scale were used to determine ground truth in the height estimation; shown is Tell el Bazari, compare to Figure 2.

ment mound probability (Figure 7). Although the specificity of these lists is high, conical elevations are not necessarily due to human settlement activity. Other georeferenced sources, such as digitized topographic maps or specific ground cover information can be used in a final step, either to separate elevations of natural origin or to confirm the probable tell identification. These locations can then be further investigated, either by the purchase of high-resolution imagery, or in the field.

Results

To evaluate the performance of this classification approach, we applied the method to the test region of the 133 archaeologically confirmed tell sites. While the detection accuracy is of major interest when evaluating this performance, another physical site parameter is valuable when analysing the classifier: the height of the settlement mound above the surrounding area. While some part of the height of the original mound may be concealed by subsequent natural aggradation of the plain, this is likely to be a small propor-

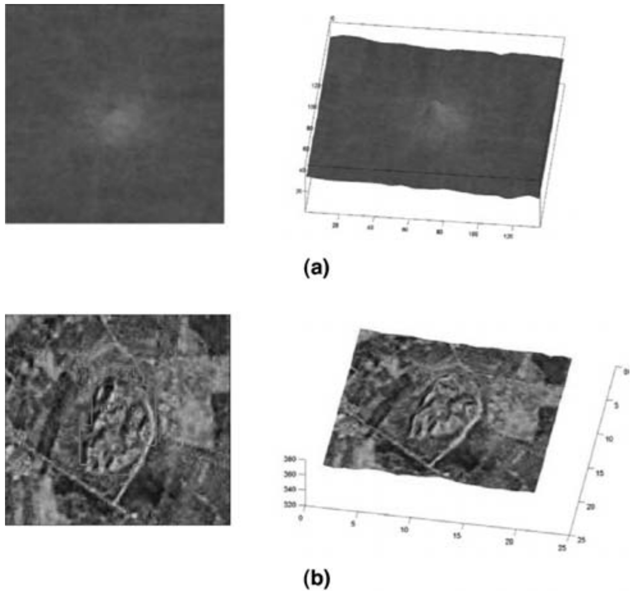


Figure 5. (a) Landsat image and elevation model averaged over all sites of the test set. The majority of the tells is in direct vicinity to modern settlement which is visible from the bright central spot; (b) Tell Brak, a major settlement site in the Khabur basin (northern direction to the left).

tion of its total height, so that height above the surrounding area is a meaningful measure. The height of a tell is mainly a function of the intensity of occupation and the longevity of the site, so that some degree of correlation between height and area may be expected.

Tell Height

This quantity was assessed from the DEM as follows: a linear plane was fit repeatedly (20 times) by least-squares onto varying subsets (two-thirds) of the neighboring SRTM pixel of each tell site in order to serve as an approximation for the base of the tell. The tell height was estimated by the maximum difference between tell surface and ground plane. We find that the smallest sites are not higher than 2 m in the DEM, while the biggest settlement mound rises as high as 30 m above the surrounding area (Figure 9). Although the variation of the height is well below one meter (even for major tells), significant errors can be observed for small sites which hardly stand out from the ground or on settlement mounds of sizes which are not (yet) represented by the training set (Figures 10 and 11).

For a subset of the tell sites the height from base to top could be determined from topographic maps (Figure 9). This allows an assessment how well the height of such small conical mounds can be assessed from the SRTM data: a first order approximation between SRTM elevation and the base-to-top height of a settlement mound suggests that the latter is underestimated by a factor of two. However, comparing the spatial average of the three arc-second SRTM model with the extensions of a tell's peak, this result had to be expected. In the following we will generally refer to the SRTM height.

Tell Detection

When applying the classification algorithm to the SRTM test tile, it is possible to detect 85 out of the 133 test sites at a threshold, which results in 327 false positives for the 600*1200 pixels of the test region (northern half of the test tile). False positives are mostly due to natural elevations resembling tells in height and size, which occur frequently in the undulating slopes of the "jebel" in the southern half of the test tile or are due to easily distinguishable artifacts caused by the presence of water surfaces. Obviously the first of these error sources sets natural limits to the presented application.

In order to understand the false negatives (the undetected tell sites) a more detailed view on the characteristic tell shape is helpful: in the earlier study of the training set, the spatial extensions of the sites had been outlined on georeferenced Corona imagery at a spatial resolution of 2 to 6 m. In a comparison between this area and the height from SRTM data, a strong relation can be observed (Figure 11): diameter and height of the tells vary linearly (area = c* height^2) indicating a characteristic shape of a settlement mound over a wide range of size. Sites which are successfully detected by the proposed algorithm follow this relation (Menze *et al.*, 2005b). Likely to be missed by the classifier is a low number of sites, which do not show the typical height/area ratio. An extension of the training data set by prototypes of these sites might alleviate this (current) drawback.

Overall, a sharp increase in the detection probability can be noted for sites with a height of more than 5 to 6 m in the SRTM data (Figures 10 and 11). Although the base-to-top height of these sites might be somewhat higher in real, this coincides very well with the limits of the SRTM data accuracy.

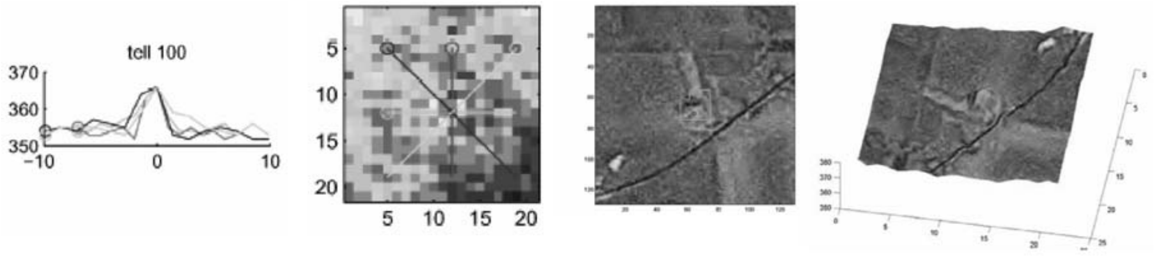


Figure 6. Principle of point detection. The characteristic height profile of a tell site generates a typical point-like pattern in the DEM. Under the resolution of the SRTM DEM, their elevation is often of nearly conical shape (height profiles left, as indicated in the DEM image patch).

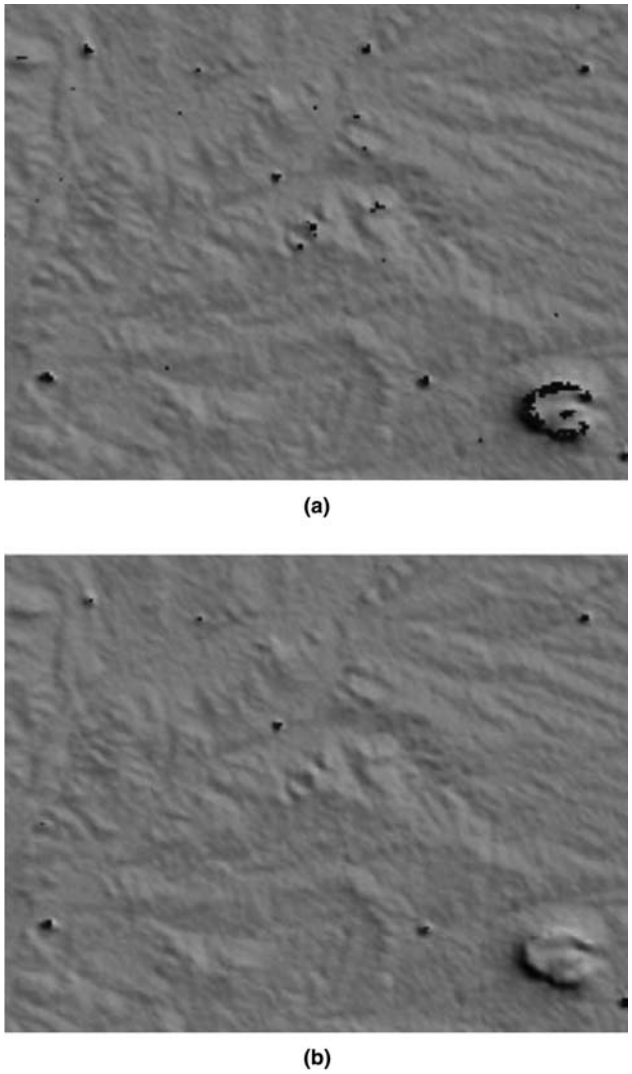


Figure 7. While a standard matched filter (a) marks a considerable number of false positive hits (see black labelled pixels), preventing any computer-aided detection of settlement mounds, the designed classifier (b) flags only a limited number of pixels with high specificity, allowing a time-efficient localization in high-resolution Landsat images in a subsequent step. (The elevation in the right lower corner is of volcanic origin and has a diameter of approximately 2 km.)

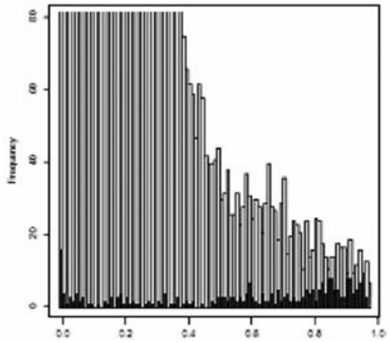


Figure 8. Histogram of the cross-validated classification results on the training data. While the majority of the 50,000 *non-tell* pixels (white) are assigned to low probability values (frequency truncated at 80), most of the *tell* pixels (dark) are gathered at high values.

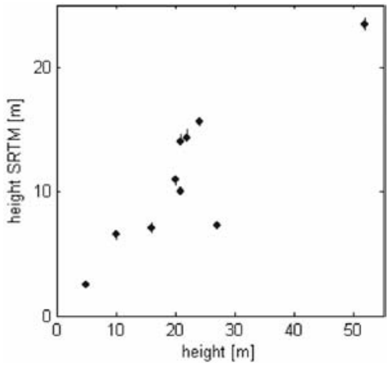


Figure 9. Tell heights of the SRTM model tend to underestimate the real base-to-top height of the mound (from topographic maps) systematically.

Discussion

Within the searched part of the SRTM elevation model, the proposed methodology is able to record settlement mounds even of minor size and to obtain positional information which is unprecedented for most of these sites.

While accuracy and resolution of the three arc-second SRTM data provides the means with which to detect elevations of tell size, a more precise assessment of their height remains a concern until a future release of the one arc-second model. So far, the additional use of satellite imagery will help in the confirmation of probable tell sites and the determination of their extents.

The proposed algorithm has been trained and tested on settlement mounds in the northern part of Mesopotamia. As tells of other areas differ somewhat in size and height, the application of the method in new regions would benefit from further training data in the form of already-known sites from the regions concerned.

In general, we envisage a program of archaeological "virtual survey" for settlement mounds over a large part of the Near East. The combination of quantitative methods (which are indispensable in a systematic screening of large quantities of data) with the globally available SRTM elevation model allows for the first time an archaeological remote sensing methodology of wide areas. This considerably extends the current application of satellite imagery in restricted survey regions.

Currently, the proposed algorithm is being applied both to regions, where survey data offer a comparison with ground-derived records, and to areas not so far systematically subjected to ground-survey in Turkey, Syria, Iran, and Iraq. These investigations are yielding new settlement sites and providing precise positional information for ones already known. Overall, the three arc-second SRTM data has made a contribution in this field of archaeology which is

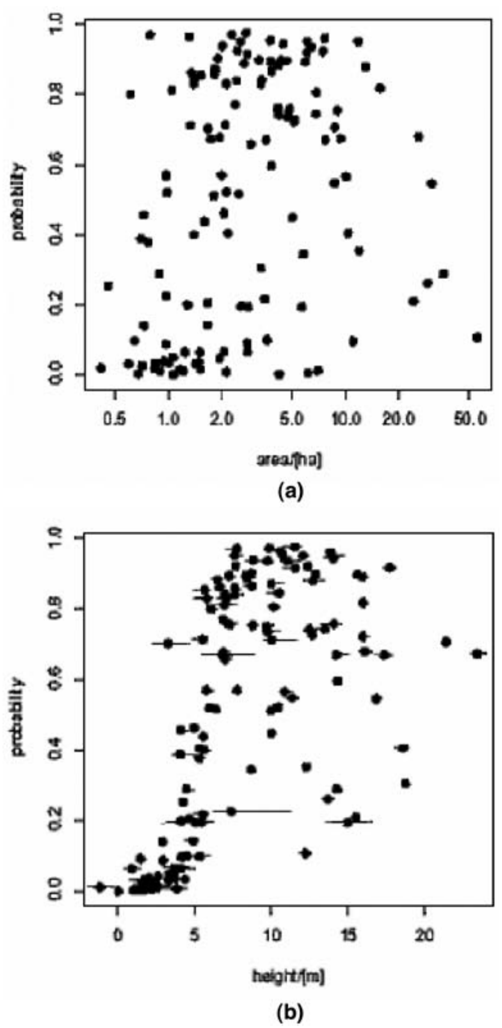


Figure 10. The detection probability of the tell sites in the test region increases for area sizes bigger than 1 to 2 ha (approximately 1 to 2 SRTM pixels) (a). The elevation of a tell is the more important characteristic (b). A *transition* in the detection probability can be observed for mounds standing out higher than 5 to 6 m from the ground (also see the discussion in the text).

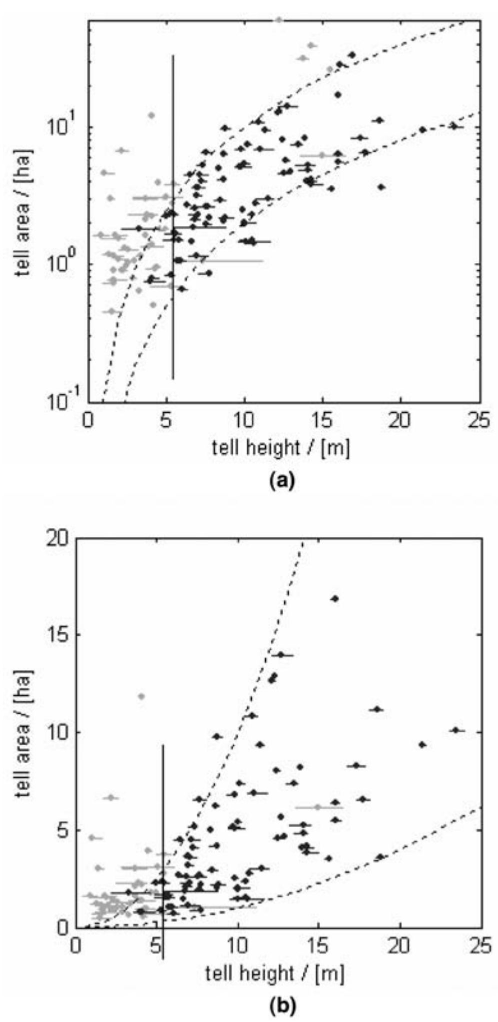


Figure 11. Out of the 133 tells in the test set, 85 could be detected (dark points) at the chosen threshold of 0.3 (Figure 8). The plot of tell area versus tell height ((a) linear area-scale, (b) log area-scale) reveals that detected sites are typically higher than 5 to 6 m (vertical black line) and follow a quadratic area-height relation (dotted lines, see text).

little short of revolutionary and will be of major importance in studying the history of settlement in this important region and in helping to conserve its remains. Additional information is available at **http://archatlas.org**.

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