Honours Thesis

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Abstract

Over the last century there have been dramatic developments in the field of remote sensing, especially passive techniques. Passive techniques include vertical photography, aerial photography, and satellite imagery. The goal of this paper is to present the history of these developments and new applications they hold for archaeologists. Satellite imagery will be used in two cases studies on the Island of Antikythera, Greece. The first case study will examine the processes of terrace mapping using high resolution satellite imagery. The second will examine the technique of rating vegetation levels through satellite imagery for correlation with visibility recorded by field surveyors. This will be used to asses the potential of applying statistical compensation for the effects visibility has on artifact recovery.

Remote Sensing: Vertical Photography

There are many different methods of conducting remote sensing, three of which are explored in this paper. This section pertains to vertical photography and the use of on-ground apparatuses to record archaeological remains. This will be broken down into three sections, discussing the terms and technical aspects, development of these devices, and finally modern examples and possible avenues of use.

Vertical photography has been used in conjunction with archaeological work since the early 20th century. This has facilitated many developments in the field. Fine tuning of this technique provides accurate, informative, and cost effective information. The method of vertical photography being examined predominantly includes the use of equipment that raises a camera to a relatively high altitude, four meters or more, using ground based equipment. These apparatuses are practicing a technique called photogrammetry which simply means surveying and mapping sites using photography (Conolly, Lake 2006: 74). This can be done on a variety of different spatial levels. The use of such a techniques allows for many specific applications including localized features, entire site records, panoramic and oblique records (Sterud, Pratt 1975: 153). When photogrammetry is conducted with ground controlled cameras, it is called terrestrial or close-range photogrammetry (Fussell 1982: 157). Recording localized features with vertical photography is an extremely important asset to all archaeological research, allowing re-visitation to important artifacts, small site areas, and architecture while containing their contextual data. This method requires the camera to be raised to a height that allows the subject to be contained preferably within one image but more are considered acceptable (Sterud, Pratt 1975: 153).

Entire sites can also be photographed using photogrammetry, seizing the current position of excavation. Allowing entire horizons of excavations to be recorded, facilitating later excavations near the original ones to be compared to the photographs for stratigraphic information and connections. This saves much time in the physical drawing of features (Sterud, Pratt 1975: 154), even though these hand drawn and measured depictions are still extremely useful and in most cases necessary. This requires the use of much larger apparatus due to the greater height needed to acquire these images. These are referred to as boom devices (Sterud, Pratt 1975: 154). Although advantageous these are costly. Similar to many methods of remote sensing this method allows for many more large scale physical phenomena to be discovered and recorded, for example changes in the soil composition or post-hole patterns (Sterud, Pratt 1975: 154). With these benefits come costs, in the form of heavy and large equipment that is awkward to move around the site. Slopes, irregular soil and other topographic features create problems, some of which can be overcome by attached levelling devices (Sterud, Pratt 1975: 154). A mount that allows an individual to directly handle the camera saves in time, pictures, and eliminates focus issues. In the right situations the advantages definitely outweigh the costs.

Image Manipulation

Pre Picture Taking

Panoramic and oblique photos provide a much larger view of the site being studied. These pictures are suggested for slides and general overviews (Sterud, Pratt 1975: 154). To add to the appreciation of these images they can be taking on an oblique angle, different angles, at different times of the day and lighting conditions, which highlights different features of the site, sometimes even presenting aspects of the site that may have been previously overlooked (Sterud, Pratt 1975: 154). The use of such a high level camera at oblique angles may also provide important landscape information allowing a better contextual perspective to the site, often overlooked in much archaeological work. The use of oblique angles has its own problems; distortion will increase especially along the periphery of the image. A directly vertical images is suggested because of its increased versatility of uses; publishing, accuracy, reproduction in drawings, and systematic overlays (Sterud, Pratt 1975: 154). The idea of increasing and decreasing different emphasis of the feature can be useful for image interpretation (Sutton, Arkush 2002: 326). Systematically overlaying different pictures of the same features at different levels of excavation is beneficial in aspect of post-excavation site interpretation (Sterud, Pratt 1975: 154). One can see the benefits that become available to archaeologists by implementing photogrammetry when recording localized features.

Another important aspect is the preparation of the subject especially when there is a desire to mosaic the images after. The transitional areas between individual frames have to be identified. This is simple in some cases where excavation pits are done in exact dimensions but when they are not it will need to be indicated. This can be done by placing a string grid over the feature/site or by putting down crosshairs in the corner of the pictures.

Picture Taking

When taking these pictures certain issues must be addressed. The first factor to consider is the lighting. Shadows become both friend and enemy. Most apparatuses used to hoist the camera above the subject run into the same problem: their legs cast shadows in the picture. There are a few ways to overcome this; throw a trap over the whole thing and use a flash, wait until night time and then use a flash, or take the pictures on overcast days to prevent the majority of the shadows. The second issue is the time of day at which the picture is taken at. This is due to the positioning of the sun and the shadows that are cast from the feature being photographed. It is suggested to take the pictures near midday when the sun is directly above the feature or, early morning or late afternoon when the sun has little effect (Sterud, Pratt 1975: 162). The third factor which ties into these lighting issues is the manipulation of shadows. This is important to understand because it can have a dramatic effect on the pictures and help emphasize certain features by lengthening their shadows and therefore making them more predominant and visible (Sutton, Arkush 2002: 326). One must also be careful when photographing features that have been excavated to a lower level then surrounding soil. The shadows can affect the subject. This can be overcome by taking the picture with the sun directly on top or by redirecting the sunlight into the pit or using artificial lighting (Sterud, Pratt 1975: 162).

Post Picture Taking

There are techniques applied to the picture after it is taken that can have a dramatic effect on their outcome. The first and necessary technique occurs in the dark room where the images are adjusted to clear up the distortion that can occur on the edges. This distortion is caused by taking pictures of elongated features. This can be avoided by using only the central parts of the picture for mosaics (Poulter, Kerslake 1997: 226). Recently, the development of digital photography has facilitated a whole new suite of image manipulation using computer operated programs. One of the most common programs is Adobe Photoshop which provides two important benefits; archiving images, and image manipulation. Recently there has been an investment into the archiving and manipulation of raw images. A raw image is the bases on which every picture is taken, a basic image in grey scale. Grey scale is a grid of different scales of grey in the form of a 12 bit image (Fraser 2004: 1). This then can be further manipulated by colour filters and compressed, usually occurring all at once within the camera, although in the process the image is reduced to 8 bits restricting further modification. The majority of digital cameras will contain two images for every picture, the raw and the colour (Fraser 2004: 2). These raw images are often referred to as digital negative (DNG) (Adobe 2004: 9). With the developing interest in DNG, Adobe has created a program that is versatile enough to accept a variety of DNG formats from different cameras and companies, also allowing for the addition of new formats so that the images will remain consistent with developing technology (Adobe 2004: 9, 10). The pictures can be stored and filed in a variety of different referencing systems with the capability of holding thousands of images (Adobe 2004: 11). This is beneficial to archaeological interpretation because it provides a wealth of images at the fingertips of the researcher and the ability to compare and examine different images all at once. The manipulation of these images has also become much easier and more accurate then ever before. Images can be manipulated to change the lighting, contrast, and colour; to correct distorted edges; to fixes lens issues; to change image sizes while maintaining image quality; to fix distortion; to reduce noise; and to sharpen the image (Adobe 2004: 10). This is all maintained in an easy interface module (Fig: 1) and can be performed on multiple images at the same time. These new developments have brought the concepts of photography to a new level over the last few years and have opened up a variety of new ways of storage, analysis, and display to the field of archaeology.

(Figure 1: Adobe Photoshop module, www.adobe.com)

The next procedure that needs explaining is creating a mosaic of the pictures; this is essential to photogrammetry. This is a fairly simple process in which many pictures are matched up with each other to create a larger picture that covers the entire site or feature. This should be done when more then two pictures depict the same feature (Sterud, Pratt 1975: 163). The images selected can be regulated by grid or have conjoining ground points in which to match them up. This facilitates the analysis of larger phenomena than available in smaller pictures.

When using close-range photogrammetry one needs to create stereo-photographs which involve several pictures of the subject from different angles. These are then examined under a stereoscope. A binocular, eyepiece that examines the overlapping area of the image making it appear in three dimensions. This is due to the human eyes being several centimetres apart causing the brain to receive the image in two slightly different perspectives and these differences are perceived as depth (Fussell 1982: 157). The images need to be reconstructed in a measuring instrument to be measured photogrammetrically. Stereo pair images allow for the complete 3D measuring without the necessity of any ground recording, especially useful upon sites of considerable irregularity or where there are standing architectural remains. There needs to be precise information about the camera, focal length, and camera calibrations to measure the subject accurately (Fussell 1982: 157). While there are some cameras that have internal calibration systems these tend to be more expensive. These devices range in precision, size, and price; in some cases they are restricted to lab use.

Development

The physical design of the equipment used to acquire these pictures can range from extremely simple designs to very complex. The early appearance of vertical photography in the archaeological field allowed for a great deal of development in the field over the years, refining and overcoming problems. These will be examined in a chronological manner pointing out each accomplishment, to properly introduce the more modern and developed techniques and technology.

In 1928 Karl Kriegler developed one of the earliest devices for vertical photography, which was used to depict burials. The device had two 3 m legs anchored to the ground with pointed pegs, joined at the top with a platform in which to screw in the camera (Sterud, Pratt 1975: 156). The mount was pulled up vertically by guide wires over the feature (Sterud, Pratt 1975: 156). This was a very good start to the development of camera mounts, lightweight, simple, and easy to use. The problems that were encountered include distortion in the sides of the picture. This could be overcome through manipulations in the darkroom.

The next major development was by Peter Pratt, developing a transit tripod with extension legs of 4.5m dowel with flat feet to prevent disturbing the archaeological remains. A camera man would use a step ladder with similarly equipped feet, to work the 35mm SLR camera (Sterud, Pratt 1975: 157). The benefit of this design was the ability to capture squared areas over and over without distortion until desired results were acquired (Sterud, Pratt 1975: 157). There were two disadvantages to this design, first was the large amount of setup and operation time needed and the second was that the legs would cast shadows on the subject (Poulter, Kerslake 1997: 222).

Peter Pratt developed another device with the help of Garyson Mitchell. They developed a tetrapod with telescopic legs allowing the increased height of 6m. This can be moved around by two people, who can take pictures of square units of 1.5m square at 4m height, and 2m square at 6m without distortion (Sterud, Pratt 1975: 159). The advantage of this device is that it has a built in ladder for the camera man to ascend, allowing rapid operation and centering of the camera. The mount can be accurately adjusted for varying slopes with the use of a clinometer. The whole assembly can be disassembled down to a size that can fit on the roof of a car within ten minutes. It is also capable of taking oblique pictures. The major setback to this device is that the legs again cast shadows on the subject though this can be avoided with a tarp and a flash (Sterud, Pratt 1975: 160).

The development of turret photography stems back to O. Fradin who used it for the first time on an archaeological site in the early 1930s to photograph burials in southern Sweden (Sterud, Pratt 1975:158). There is little recorded about it though. The use of the turret is seen again during the Second World War in which a three legged turret eight meter high was designed. This involved a camera platform where the camera was hauled up by rope and then activated on the ground by an electronic switch (Sterud, Pratt 1975:158). In conjunction with this turret another was used, though it used a stationary mast extending beyond the meeting place of the three legs making it much less versatile. These turrets were well developed for recording individual features and oblique pictures. It was also very economical, costing only $100 (Sterud, Pratt 1975:158).

The structure of the turret was developed over time by archaeologists such as Franze Hample in the 1950s who used a bipedal turret with independent telescopic legs to account for variation in terrain (Sterud, Pratt 1975:158). Wiltshire developed a single pole design for taking oblique pictures of megalithic monuments. It was aimed by means of a telescope. The application of a second camera was available (Sterud, Pratt 1975: 158).

While there were many minor adjustments to these devices there are two major contributions that still warrant discussion. First was Erik Nylen, who after a decade of fine tuning, developed a tripod mount that extended telescopically from 3m to 16m (Sterud, Pratt 1975: 160). The apparatus, 63kg, could be put together in under half an hour and was triggered remotely. It could take pictures that covered an area from 5-6m to 8-10m squared. The disadvantages were that it took four people to use; it was affected by wind, and was extremely fragile. The total cost of this turret was $800 (Sterud, Pratt 1975: 160).

The second development was made by Wittlesey, it was thought to be the most successful turret (Sterud, Pratt 1975: 161). The device was designed as a 12m biped with telescopic legs stabilized by guide wires (Sterud, Pratt 1975: 161). The apparatus had the ability to take stereo-pair pictures and photogrammetric images, recording from 20 sqm to 100sqm. This device was very light and could be operated by two people (Sterud, Pratt 1975: 161). Wittlesey has gone further to develop backpack sized apparatus to be carried to remote sites, sized to 4.5 ft. The apparatus can capture images of an area 3m x 4.4m and weighs less than 10 lbs (Sterud, Pratt 1975: 162).

Modern Equipment

The most modern equipment to be examined in this paper was developed by Tony Holm, chief photographer, University of Nottingham, as described in the paper by Poulter and Kerslake, *Vertical Photographic Site Recording: The Holmes Boom*. This article dealing with the site of Nicopolis ad Istrum, a Late Roman site that lasted to become an early Byzantine city. The site is 5.7 ha in size located in northern Bulgaria (Poulter, Kerslake 1997: 221). What prompted this work was that kite and helicopter photographs were found to be inappropriate for the surface features within large excavated areas while at the same time conventional plan drawings were too time consuming and also unsatisfactory (Poulter, Kerslake 1997: 221). This spurred the use of a boom apparatus to take the pictures of the entire site and replace the interpretative site plans. To do so a new apparatus had to be created.

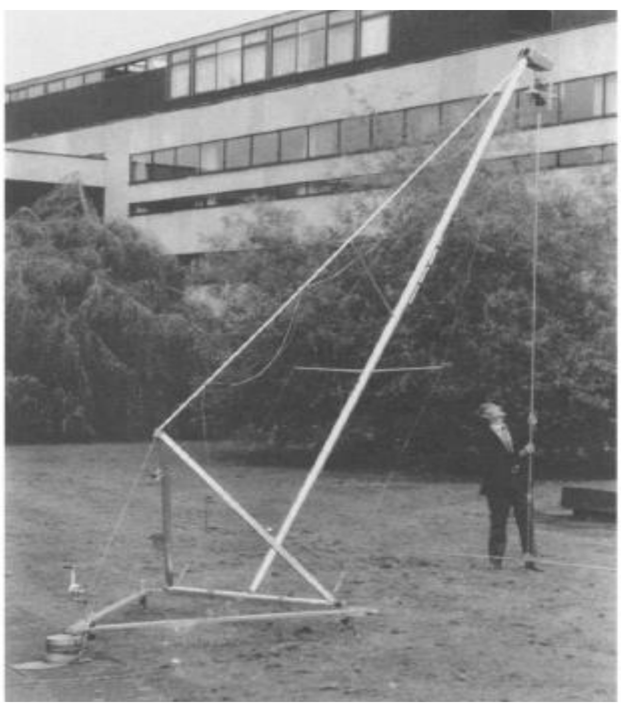
The development of this new device was based around the certain needs of the project. These needs have been seen previously with the development of these vertical photography stations.

- Stereo-pairs of photographs
- Easy assemblage
- Small
- Light weight
- Sturdy (eight week field season)
- Two people operative
- No shadow interference
- Useable on flat and steep terrain
- Low manufacture cost

With these goals in mind Tony Holm set out to build this device. His first step was to recruit a friend, David Oakland, Engineering Faculty Workshop, University of Nottingham (Poulter, Kerslake 1997: 221). They accomplished this task in eight months for £100. The prototype was used in the 1987 season, but before any modification, Holms died to the regret of many. The Holmes Boom went on to be used in 1988 for five seasons (Fig: 2) (Poulter, Kerslake 1997: 221).

The Holmes Boom was designed to accomplish the listed goals. To do so it had combined previously used traits with new designs. It used an extended boom arm that overcame the shadow issue. Because it was so far from the base, it only had to be positioned on the opposite side of the sun (Poulter, Kerslake 1997: 222). The device was lightweight but extremely strong at the same time. The base of the unit sat on rubber pads so as to have little effect on the site. The camera was designed to take two pictures at each interval. The first was without a scale to be properly adjusted and placed in context and the second was pristine and used in publishing (Poulter, Kerslake 1997: 224). Then the boom was moved on allowing for a thirty percent overlap for mosaics (Poulter, Kerslake 1997: 225). At the same time the camera was allowed to swivel to take oblique photographs. To produce the required stereo-pair images the camera was allowed to take pictures with 60% overlap (Poulter, Kerslake 1997: 225). While this was only a prototype and improvements have been suggested. One is that a video feed should run from the camera to a monitor at the base (Poulter, Kerslake 1997: 231).

The Holmes Boom was found to go above and beyond what was expected which is why it is held in high regard in this paper. The evidence it produced at the Nicopolis ad Istrum and a subsequent Roman road. On the Roman road it accomplished six to ten stations an hour attesting for its speed.



(Figure 2: Holmes Boom, Poulter, Kerslake 1997: 231)

Photogrammetry's Applications

There are many benefits for terrestrial photography. Archaeologists tend to be very inventive when developing methods for vertical photography. In one case they mounted cameras on wires suspended over the site by two towers, in another case cameras were attached to under water airplanes for underwater photography (Fussell 1982: 158). Photogrammetry is fast and easy to do therefore barely interrupting excavation, excellent for rescue work. An example of this is the Catacombs in Berlin. Recording four skeletons in a morning far surpassed the day and a half recording one skeleton with conventional methods (Fussell 1982: 162). It allows for the examination of artifacts post-excavations, especially when working in foreign countries (Fussell 1982: 162). If available during excavation, they can be used to create work plans, exhibiting certain aspects of the excavation unit (Fussell 1982: 163). This saves on the time spent on recording and measuring the site, even providing more accurate information. An example of this is the excavations in Jordan. The excavation of hundreds of tombs in Petra were all photographed and classified into cultural phases at a later date away from the site (Fussell 1982: 163). It can be used for restoration and relocating projects, for example the work along the Nile when the Aswan dam was built (Fussell 1982: 162). Using photogrammetry reduces the physical contact with the artifact therefore better preserving it. Rivett recorded a large amount of rock art in Australia working with fragile limestone, even creating models using a modified stereoscope (Fussell 1982: 163). This also allows access to images of inaccessible archaeological sites and artifacts (Fussell 1982: 163).

Conclusion

Through the years of development these apparatus have overcome many problems that have held them back, issues such as lighting, weight, size, durability, costs, and accessibility. The terrestrial aspect of vertical photography has proven to be an extremely useful tool for archaeologists in all sorts of different situations around the world. They provide important databases for post-excavation examination on many different scales, small find context, trenches and other excavation units, entire sites, and landscape analysis. These images have become indispensable to modern archaeological excavation whatever apparatus used.

Remote Sensing: Aerial Photography

Aerial photography will be studied, using the system of history and development, available resources and techniques, and individual case studies. It is important to discuss the history just as much as the devices used. This is to provide necessary background and understanding but also the history is interlinked with the resources that archaeologists can draw upon. Starting just after World War One aerial photography from planes became recognised as a valuable resource for archaeologists, seen by examining original works by three prominent archaeologists of this time, O.G S. Crawford, Antoine Poidebarb, and later Jean Baradez. Similar to the analysis of vertical photography, the paper will progress through time, finishing with recent works by people such as Kevin O. Pope, Bruce H. Dahlin, Eyal Ben-Dor, Juval Portugali, Moshe Kochavi, Michal Shimoni, and Lipaz Vinitzky. This will be including the resources available to the public, costs, and possible applications.

Development

The importance of aerial photography became widely known to archaeologists after World War One. This was definitely not the first time it has been used though; J. E. Capper utilized it in his study of Stonehenge in 1900 (Capper 1907: 571). By attaching a camera to a war balloon he was able to acquire many pictures of Stonehenge that facilitated its study from a new perspective, both physically and metaphorically.

One of the first promoters of aerial photography was O. G. S. Crawford (Fig: 3). Though he was not the first one to use this method, he brought it to the public eye. The importance of this resource became apparent to him when he was in the military serving in the Survey Division of the Third Army and as an observer in the Royal Flying Corps. After the war he attempted to gain access to military pictures but was denied. He got his chance when invited by Dr Williams-Freeman to examine some aerial pictures from the current RAF Commodore (Crawford 1960: 46). These images depicted plans of a Hampshire field system, over 2000 years old. Crawford followed this up with intensive field work and new aerial pictures. Then they presented the results to the Royal Geographical Society and published in the *Geographical Journal* in 1923. After all these proceedings, it was concluded these pictures provided certain benefits. First is that it contained all the properties of a manuscripts except that it could be replaced (Crawford 1960: 46). Secondly it can be studied at leisure anywhere, at the same time being compared to other images and maps (Crawford 1960: 46). This work inspired Crawford to develop a methodology of classification of ancient sites seen in these aerial images; shadow-sites, soil-sites, crop-site (Crawford 1960: 46). These classifications created in the 1920s were self-explanatory and proved adequate until well after the 1960s, used all over the world. Crawford continued his work in collaboration with Alexander Keiller writing a book called *Wessex from the Air*. Others have followed in his footsteps such as Makor George Allen who worked in Oxford, bequeathing his collection to the Ashmolean Museum upon his death (Crawford 1960: 47). Around the same time Father Poidebard was working in Syria with the French Air Force. He pioneered flights across the Syrian Desert to the Euphrates and then High Jazirch. He examined Roman frontier defences and roads, documenting many for the first time. Most interesting is that Poidebard pioneered the photography of underwater remains at the site of Tyre, from the air and from below water (Crawford 1960: 47).

(Figure 3: O. G. S. Crawford, <http://ads.ahds.ac.uk/images/catalogue/ogs.jpg>)

Aerial photography work is conducted all over the world, with spectacular results. One area that will be examined is Peru where Lieutenant Johnson and the geologist Shippee conducted work in 1931. This was the first time any effort to systematically use "aerial photography to discover, locate, and describe prehistoric ruins and agricultural features in South America" (Denevan 1993: 238-239). There was previous photographic work conducted in Central and South America, as in Lindbergh work in 1929 with the pueblos of New Mexico and Mayan causeways and cities in the Yucatan (Denevan 1993:239). Chan Chan in Peru has undergone work as well by Holstein (Denevan 1993:239). The work conducted by Shippee and Johnson was in Southern Peru in the Colca Valley. They logged four hundred and fifty four hours of flight time during which they photographed, The Great Wall of Peru, many prehistoric ruins terraces and irrigation systems. They also managed to capture Cuzco, the Urubamba Valley, Hunacayo Lima and the southern coast, Arequipa, and the Andagua Valley. These involved five hundred and fifty vertical aerial photographs at 1:13000 scale, while there were 2450 oblique photographs, and a 1000 ground photographs (Denevan 1993:248). These pictures provided a large database for archaeologists interested in Peruvian archaeology, though much of the collection is incomplete and spread all over North America.

The development of aerial photography is tied in with war efforts and the technological race that war brings with it. This has proven to be beneficial for aerial photography and has speeded up its development. The military has also developed a large photographic database to which archaeologists are permitted access to. These are useful especially in modern work because the pictures were taken prior to large amounts of modern expansion. This resource has been developed as a necessary tool for many archaeologists working in a variety of different projects.

Methodology

Aerial photography helps archaeologists understand the amount of human labour invested in manipulating the landscape. They pick up minute banks and silted in ditches that would have required many hours of labour but today are barely noticeable (Crawford 1960: 48). Aerial photography is able to reveal undulations in the surface that are so slight and broad that they are often missed by field walkers. When field walkers have the print in hand, they can more readily pick up on these discrete characteristics (Crawford 1960: 48).

One of the great contributions that Crawford has contributed to aerial photography was the classification of site interpretations based on their depiction in the images. These are as follows:

Shadow-sites: have surface irregularity, consisting of banks, mounds, ditches, and terraces. They become obvious from the shadows that these obstacles create, seen in the rising or setting sun (Crawford 1960: 47). These are noted to be similar to photographing inscribed stones and carvings. These sites are not always represented by shadows but the lack of. On slopes facing the sun they appear as brighter lines or foreshortened shadows. Sometimes these can be seen from the ground but aerial photography brings more to light, metaphorically.

Soil-Sites: revealed by disturbances and consequent discoloration of the surface. These are most predominant in fields when the crops are not present. They are caused by the dispersal of banks, mounds, roads, and ditches, especially when chalk is used to base them. These can become visible in bare soil as well, ditches become visible even when filled in and physically indecipherable from the other areas. This is because of the moisture the filler contains making it appear darker (Crawford 1960: 48). The best time of year that these sites become more apparent is during the spring or fall when vegetation is at a minimum. It is noted though that soil-sites will sometime become crop-sites later in the year when covered with vegetation.

Crop-Sites: Crawford expresses these are the most important and numerous of all site types (Crawford 1960: 48). These sites are noticed by discrepancies in crops. This is caused by greater moisture in the soil, similar to the ditches in soil-sites, except the site has been covered in crops. The plants grow better in the areas that have been filled with silt; this causes them to appear darker green in the photos (Crawford 1960: 48). Roads and other solid foundations under the soil stunt the growth. This makes the style of crop-sites very dependent on soil, weather, crop type, and archaeological remains present (Joseph 1945: 52). An important aspect to these sites is that they do not deteriorate over time. A very important discovery using the crop-site method was a group of Neolithic and Early Bronze Age sites in Italy. Discovered by John Bradford at the end of World War Two, they depict many hill forts and encircling ditches with excellent sharpness and accuracy.

Case Studies

The goal of this paper is to describe the many applications of this method of remote sensing. Aerial photography has been known and utilized a great deal over the last few decades. Archaeologists are always experimenting in new locations and with new methods. Moving beyond the historical uses and development, more recent studies will be examined. By including these modern case studies the goal is to introduce the readers to the great amount of possibilities and new technological developments.

Airborne Thermal Video Radiometry and Excavation: Planning at Tel Leviah, Golan Heights, Israel

Eyal Ben-Dor, Juval Portugali, Moshe Kochavi, Michal Shimoni, Lipaz Vinitzky

The goal of this project was to derive information about sub-soil objects at an Early Bronze Age settlement called Tel Leviah using a thermal sensor mounted on a Bell 206 helicopter. This site was ideal for this study because of the thin layer of soil that covered it, ranging from around 5-50cm in depth (Ben-Dor, et al. 1999: 120). The ancient construction at this site used basalt stones in their architecture. The vegetation is classified as segetalic meaning trees with occasional shrubs. The time of day and of year they decided to do this survey was very important. As explained earlier with photogrammetry they decided to work between October and November and early in the morning before the sunrise (Ben-Dor, et al. 1999: 120). This was done to minimize the background interference such as shadows, atmospheric disruptions, and vegetation (Ben-Dor, et al. 1999: 120). They also prepared the site by removing as much of the vegetation as possible.

The aerial pictures and satellite images were restricted by optical passive sensors, film and radiation. This meant that they were restricted in the spatial and spectral coverage, limited to between 10-30m in 0.45-2.35μm or 120m in 10.4-12.5 μm (Ben-Dor, et al. 1999: 117). See chart and section Energy and Colour, for further explanation. The radar will only examine the top portion of the electromagnetic range, 0.7 to 2.5 μm. They are more interested in the thermal infrared region, TIR, 3-14 μm, more attuned to the radiation emitted from the earth's surface rather then reflected. This makes TIR good for the study of subsurface anomalies (Ben-Dor, et al. 1999: 118). The surface heat which emits the radiation is heavily dependent on certain factors of the environment. The depth of the subject is most important because TIR can only penetrate to a certain depth depending on the conditions. The daylight allows for the sun protons to be absorbed into the surface. The energy then is converted into heat flux and diffuses downwards; the depth depends on the soil density, determining the thermal conductivity and thermal capacity. In this project the soil allows for 50cm yearly and 25cm daily (Ben-Dor, et al. 1999: 118). While during the night time the soil cools with the photons travelling out of the soil which contributes its heat to the surface. This is important because any buried objects cool down at different rates depending on their different physical characteristics. This produces different surface anomalies that can be detected with TIR sensors. This is seen by the basalt architecture increasing surface temperature (Ben-Dor, et al. 1999: 125). As mentioned, these signals can be affected by different external factors which can be reduced, for example removing the vegetation.

The project was not limited to TIR sensors. They also investigated TVR, Thermal Video Radiometry, another tool for studying thermal signatures. They found that it was very sensitive when measuring the thermal energy of objects in both the micro and macro scales (Ben-Dor, et al. 1999: 118). It has an internal calibrator that converts the raw data output into a radiometric image, temperature values, thereby giving physical meaning to the images capable of detecting very small variations in temperature, greater then 0.1˚C, which is reflective of the physical and chemical characteristics (Ben-Dor, et al. 1999: 119). They found the sensor to be a very promising tool for evaluating small variation on the city's surface and it appears in almost real time. They found this method to be cost effective too, spending $1000 a day for the TVR sensor and $800 an hour for the helicopter (Ben-Dor, et al. 1999: 120).

Through the work they conducted while studying the site of Tel Leviah they developed a list of conditions that are best suited for thermal imaging. First is the temperature of the earth's surface which relates to the time of day and angle of the sun (Ben-Dor, et al. 1999: 120). Second is that the object needs to be buried within the daily heating cycle, 0-40 cm (Ben-Dor, et al. 1999: 120). Thirdly, it needs to be different in chemical makeup from the surrounding soil. Fourthly the dimensions of the object being studied needs to be bigger then the spatial resolution of the object (Ben-Dor, et al. 1999: 120). There are some restrictions for thermal imaging, for example the cost, limited spatial and spectral resolutions, and it also tends to be complicated to use.

The authors found these aerial images indispensable for their work. They were able to use photogrammetry and create mosaics like terrestrial photographs. They mounted a GPS on the TVR for positioning assisted by ground control points, created by heat beacons of small fires (Ben-Dor, et al. 1999: 121). They discovered an important buried wall that would have otherwise gone undetected (Ben-Dor, et al. 1999: 125). This project exemplifies the incredible uses and large number of applications that remote sensing has to offer in the realm of aerial photography.

Ancient Maya Wetland Agriculture: New Insights from Ecological and Remote Sensing Research

Kevin O. Pope, Bruce H. Dahlin

This project involved two forms of remote sensing, aerial photography and satellite imagery. It is important to discuss this because the article examines the benefits and disadvantages of each one, instituting each method to compensate for the each other. Pope and Dahlin were examining the agricultural patterns of the Maya in the central Maya lowlands. They were specifically interested in the canal systems, mapping and examining their different characteristics; width, depth, and length, and relating them to environmental circumstances.

They used Landsat Thematic Mapper (TM) and Seasat satellite with a synthetic aperture (SAR) (Pope, Dahlin 1989: 89). These produced images of the canal systems that were studied for distribution and their relationship to wetland hydrology and vegetation. The images produced had the resolution of thirty meters and were produced in false colour then modified through contrast stretching and edge enhancement techniques to improve the images, basing their methods on previous work with these satellites in the area (Pope, Dahlin 1989: 90). They were able to identify the linear features as possible canals if undisturbed by modern land use, thereby allowing the identification of wetlands and ancient terraces of the canal systems. This was verified through field work conducted in the areas.

The aerial photography was produced by the Jet Propulsion Laboratory, using a SAR mounted on the airplane. This method allowed for images of greater resolution at lower altitudes. The aircraft SAR was able to produce 20 'looks', images, of an area with the resolution of 15m (Pope, Dahlin 1989: 94). When combined to reduce the speckle noise the resolution increased to 20-21m. This was important because they found some inadequacies in the satellite images. Popes and Dahlin listed reasons why the satellite imagery was unusable for the identification of canals, expressing that the radar lattice did not always represent the canal systems. The lack of verification in the field, whether surveys or aerial photographs, did not help the situation. When they were verified in northern Belize, they do not appear in the images (Pope, Dahlin 1989: 94). The satellite resolution cells, 25-30m, were too large for the identification of smaller canals and associated fields (Pope, Dahlin 1989: 94). This became compounded by the speckle noise see section, Satellite Cases Studies, Donald W. Holcomb. Speckle noise is the grainy appearance of images. This was overcome by the use of aerial images that allow for the greater resolution and the detection of smaller canal systems.

One can see from the work conducted by Popes and Dahlin that there needs to be a great understanding of the geographical and environmental nature of the area being examined. They presented five types of Wetlands in the Maya Lowlands. The first is perennial swamps with river drainage through limestone terrain known as Karastic rivers. The second is perennial and seasonal swamps with river drainage through non-limestone areas such as volcanic and metamorphic terrain, Non-Karastic rivers. This is followed by perennial swamps with depressions with a permanently high water table. The fourth is seasonal swamps with depressions but with a seasonal water table. The final classification is coastal wetlands composed of saline soils with some tidal fluctuations (Pope, Dahlin 1989: 91). All of these categories have different characteristics and therefore have different agricultural techniques that prove more effective depending on the ecological circumstance. This makes their identification difficult unless there is a proper understanding of their specifications and adaptations to different environments.

‘Ground truthing’ means to physically enter the field to confirm the classifications and interpretation of the aerial images. This is needed in most remote sensing forms. It is necessary for there can be discrepancies between the interpretation and reality. This can be caused by natural phenomena like changes in soil or rock composition, elevation, or even discrepancies in the image itself. These all can cause misinterpretations of the study area, unbeknownst to the archaeologist. In this project they reference field work previously conducted in the area.

Their work was concluded to have been useful for the examination and evaluation of remote sensing in the Mesoamerica area. They stated that the satellite images were useful in the identification and mapping of large-scale spatial patterns of this diverse and inaccessible environment, identifying many cultural and natural patterns that are nearly impossible to see in the ground (Pope, Dahlin 1989: 89). The aerial photography was more useful in the examination of smaller phenomena, especially the smaller canals that can be only a few meters in width but hundreds in length (Pope, Dahlin 1989: 89). Popes and Dahlin are anxiously anticipating the developments from the Jet Propulsion Laboratory which was working on greater aerial resolution of ten meters. It is important to note here that since the publication of this paper there has indeed been great advancements in remote sensing both aerial and satellite imagery, this will be examined in the next section.

These case studies were chosen to show the wide variety of applications that aerial photography has and how it can be used in the field of remote sensing. They express that the field is constantly developing, changing in methods, applications, and technology. What else becomes apparent is that archaeological projects rarely implement just one method of remote sensing. Satellite imagery and other modes of apertures and images are presented for the first time, this will be the subject of the next section of this paper.

Conclusion

Arial photography has developed greatly since its first introduction to archaeology in the late 19th century. The interest in the military in remote sensing technology has been beneficial for its advancement and development of large worldwide databases. The applications with archaeology began as a slow expansion, owing much of its development to men such as O. G. S. Crawford and Father Poidebarb. In recent years it has been spurred on by developing technologies that allow for many new applications that were never thought possible before. The field of aerial photography and archaeological interpretation requires a lot of dedication and commitment to learn the necessary skills to be proficient in this field. The results from aerial photography are very exciting and have inspired many archaeologists to explore new avenues for its use and for further developments in remote sensing.

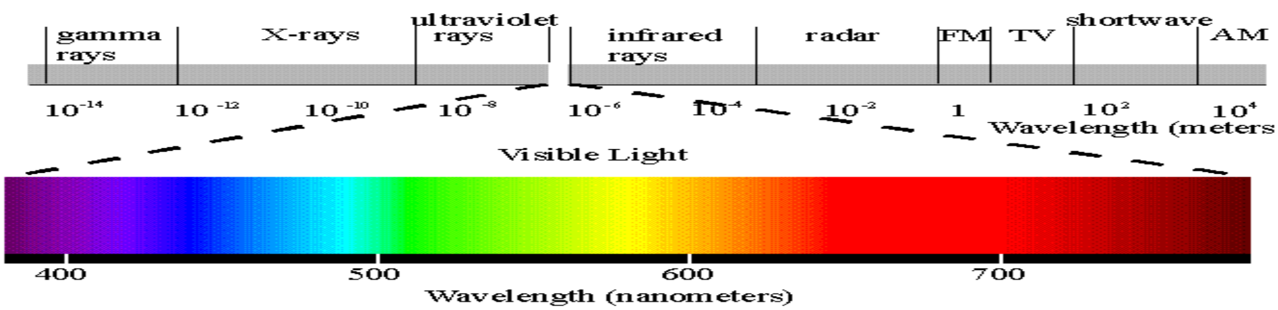
Remote Sensing and Satellites

In the following section satellite based imagery systems will be examined. First, the methodology and terminology involved in their use will be explained. This is then followed by a breakdown of the satellites available to the public today presenting the possible resources available. Finally archaeological case studies will be explored to present the possibilities that these satellites make available to archaeological studies.

Energy and Colour

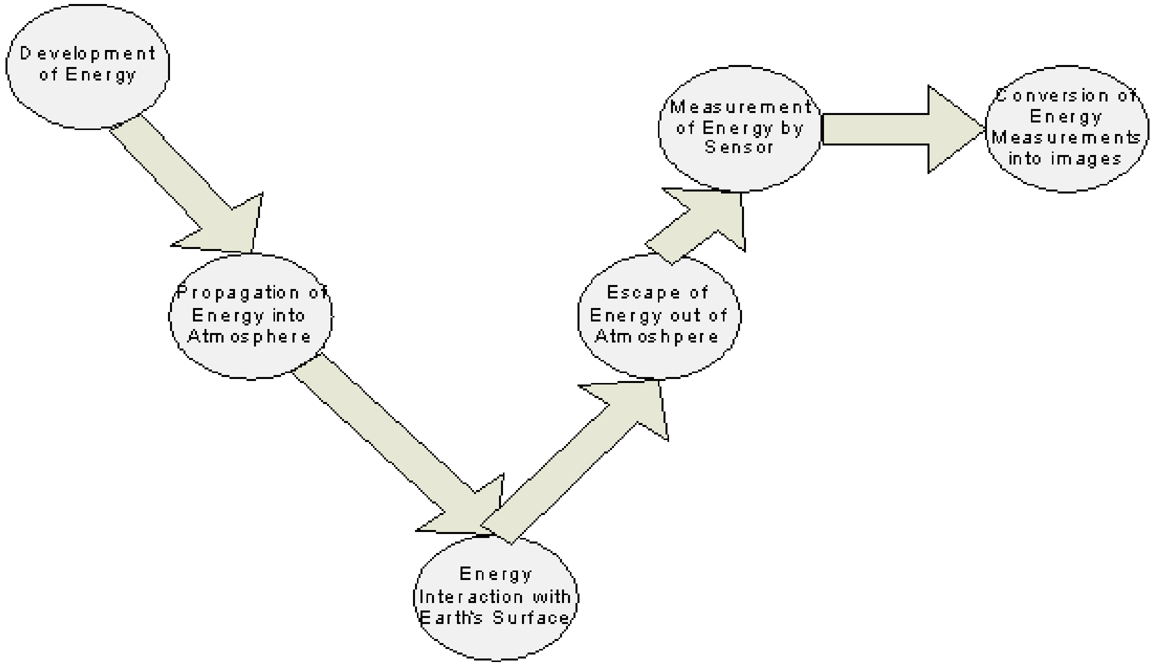
The majority of sensors mounted on satellites measure electromagnetic energy which is emitted and reflected off the Earth's surface. The source of this energy is mainly the sun but almost all matter emits electromagnetic energy. Electromagnetic energy encompasses many different wavelengths which can be mapped and examined for characteristic wavelengths. While a human eye can only perceive a small portion of electromagnetic energy called visible light, there are sensors that can view much more.

The most popular forms of this energy include radiowaves, thermal, ultraviolet, and x-rays (Lillesand, Kiefer 2000: 4). Electromagnetic energy is ruled by wave theory; "travelling in harmonic, sinusoidal fashion at the velocity of light ($c = \nu\lambda$[1])" (Lillesand, Kiefer 2000: 4). This allows for the categorization of different wavelengths. This is mapped on the electromagnetic spectrum, a collection of electromagnetic energy in terms of wave lengths (Fig: 4). While it might appear that these forms have clear cut divisions they are in fact indistinguishable except by the radiation emitted (Lillesand, Kiefer 2000: 4). These sensors complete one of the two processes involved in remote sensing, data acquisition. The processes involved in the data acquisition are shown in a basic flow chart (Fig: 5).



(Figure 4: Electromagnetic Spectrum)

[1] Velocity of light, c. Wave frequency, ν. Wavelength, λ.



(Figure 5: Flow chart representing the flow of energy to the sensor.)

The movement and acquisition of data is important to understand so that one can comprehend the ways in which energy can change due to its interaction with surface features and the atmosphere. Different surface features will effect the reflected energy waves. The changes in wavelengths over the spectral range for each different aspect of the earth including the vegetation are called spectral signatures (Eastman 2001: 40). The receivers in satellites interpret the data and assign it numerical values which are used by software programs such as ArcView or IDRIS to present the information in coloured maps. The effects of vegetation are important to archaeological research; chlorophyll that is present in green leaves strongly absorbs energy of wavelengths between 0.45-0.67 μm, which causes a green colour due to absorption of the red and blue. When examining the same vegetation in the spectral range closer to the near-infrared range, 0.7-1.3 μm, one is able to observe the different types of vegetation. This is because the reflectivity is based heavily on the internal make-up of the plants' leaves (Lillesand, Kiefer 2000:18). Soil is similar to vegetation in the manner that it can change in reflectivity depending on the changes in spectral ranges, but in this case it is much more subtle. It is in the range of 1.4, 1.9, and 2.7 µm, known as the water absorption bands, that the greatest difference is seen (Lillesand, Kiefer 2000: 18). This is important because like vegetation, soil is heavily influenced by other factors such as moisture, which can reverse the reflectivity of the sand depending on whether there is water or not. Texture reduces the reflectivity when the roughness increases. Texture varies with what the soil is composed of, for example silt, sand, or clay. Each spectral band is able to highlight different aspects allowing them to have unique applications. (Chart: 2). Understanding that each of the Earth's features produces its own response pattern, one can see the huge amount of possibility available to archaeologists trying to find patterns and distinguish between features on the Earth's surface.

Atmospheric Distortion

It is essential to understand that it is not only the Earth's surface which causes the changes in reflectivity but also the atmosphere. There are a few factors to consider when discussing the atmosphere and satellite imagery. The first is that the atmosphere will cause a scattering of radiation; this is an unpredictable event caused by the particles in the atmosphere. There are three kinds of scatter; rayleigh is the most common, which causes haziness to the image produced by scattered short wavelengths (Lillesand, Kiefer 2000: 9). The second is Mie scatter, seen mostly in areas with high levels of water vapour or dust, mostly with overcast images. This scatter affects the longer wavelengths (Lillesand, Kiefer 2000: 9). Nonselective scatter is when the atmospheric particles are larger then the wavelengths this causes fog and clouds to appear white in the image (Lillesand, Kiefer 2000: 10).

The second atmospheric factor to consider is absorption; this is important because it creates what is called "atmospheric windows" expressing what spectral bands are least affected by the atmospheric absorption. Causes of this absorption are mainly water vapour, carbon dioxide, and ozone (Lillesand, Kiefer 2000: 10). This restricts the user because they can not choose whichever sensor they would like to use without considering three important factors, best laid out by Lillesand and Kiefer; first the spectral sensitivity of the sensor, second the atmospheric windows, and thirdly the source, strength, and spectral composition of the energy in the selected ranges. While innovative equipment such as thermal scanners and multispectral scanners is available, it is still not an aspect to be considered lightly.

The atmosphere throws in another important twist, illumination. First is that it can reduce the energy illuminating the surface features. The second is that it acts as a reflector itself, causing extraneous paths of radiance to the signal that is being detected by the sensor (Lillesand, Kiefer 2000: 22). These two biases can be countered by applying a mathematical equation, $L_{tot} = pET/\pi + L_p$[2] (Lillesand, Kiefer 2000: 22). Just as important is how the data can be manipulated to produce different perspectives of the images. A few of the more important and popular techniques are explained below.

Sensor Types

There are many sensors that can be equipped on a satellite. They range in function and variation within each system. The most common sensor attached to a satellite is a

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[2] L_{tot}= Total spectral radiance, p= Reflectance of object, E= irradiance on object, incoming energy, T= transmission of atmosphere, L_p= path radiance, from atmosphere.

multispectral sensor, though there are many other scanners and sensors; Thematic mapper system (TM), Thermal IR Scanner, Microwave Scanner, and Synthetic Aperture Radar (SAR). Recent satellite programs such as stereo pair, anaglyph, interferometry systems, and backscatter/radar scatterometer, have been expanding the possibilities which these cameras are able to produce. They have developed panchromatic images and infrared-sensitive film. These advancements are shown in chart 2. While these are methods to manipulate the incoming data directly on-board the satellite, there are many ways in which one can use these images.

Satellite imagery has not only developed by the changes to its physical acquisition of data but also, the images themselves are now subject to manipulation in order to extract new and important data. A few of these techniques are explained in chart 3. One of the most popular methods has been experiments with colour in conjunction with signal strength and elevation. Digital elevation maps (DEM) are created through stereo pair images. These datasets are in the form of uniform grids, inlaid with elevation data, they have become increasingly important.

It is impossible to truly understand the potential of satellite imagery without discussing what platforms are available for archaeologists so they can become interactive with the maps and data. There are many programs but one in particular will be examined. Geographic Information System (GIS) a computer program capable of creating interactive maps of geographical spatial data and the manipulation of the data as well. There are many GIS programs but an overview of the program is what is being presented in this paper. GIS works by incorporating collected data, editing it, and displaying it in map form. This can be done for many data sets and almost any data that can be distributed over area. This technology was by no means created for archaeology but was integrated in to the field just the same. It initially started in 1967 in Ottawa, Ontario. It was developed by Roger Tomlinson and called 'Canadian GIS' (CGIS). It was used by the Department of Energy, Mines and Resources, for the Canadian Land Inventory, mapping soils, wildlife, forestry, and agriculture. (Wright, Goodchild, Proctor 1997: 346)

GIS has many capabilities ranging in terms of data entry and data manipulation. Data can be entered in many forms; pre-existing maps, pictures, aerial and satellite imagery, and maps of any kind such as elevation. These visible images are called raster files; consisting of rows and columns like a spread sheet, but within each cell is a stored value (Eastman 2001: 46). This value can be anything from soil acidity to artifact counts. Each cell can be further expanded and colour chosen for each value to create a map. The individual cell usually represents an area of ground but other units maybe represented. Vector, unlike raster, uses geometries; these can be points, lines, or polygons. They are representations of objects (Eastman 2001: 8). They may be artifact locations or sites with the incorporation of continuously changing values over the landscape.

Satellite Breakdown

There are five different satellites that will be examined in this chapter: SPOT, Landsat, Aster, QuickBird, and SRTM. Satellite selection was based on availability, pricing, quality of images, and importance in the development of this field. Each one will have a comprehensive examination of what they have to offer. The categories of examination are broken down into their history and working mission statements, technological breakdown; resolution, spectral bands, accuracy, and costs involved in image acquisition. This will provide a reference of what is available to archaeologists informing them of what they can choose and which unit is best suited to them and their project's individual needs.

Landsat

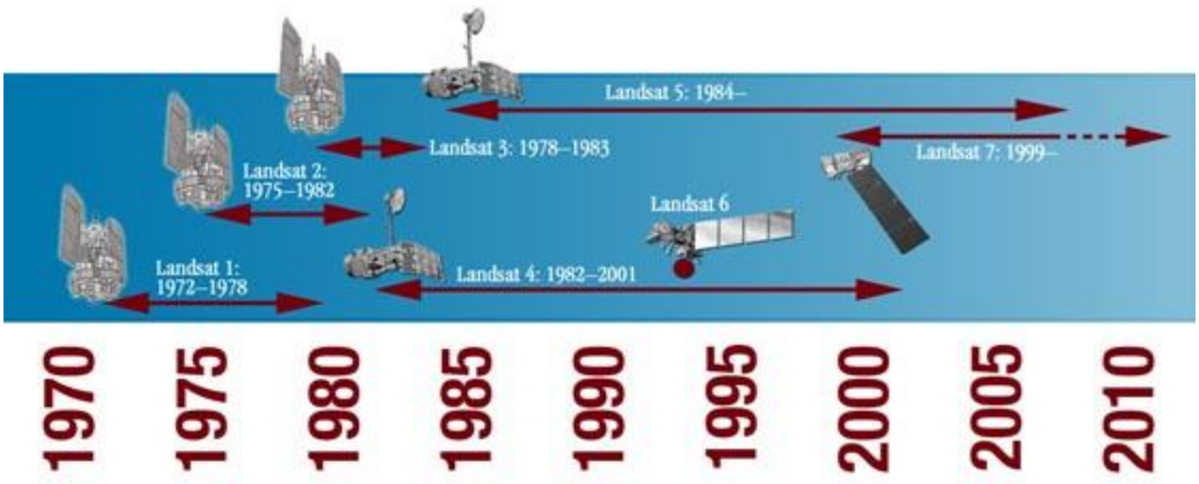
http://landsat.gsfc.nasa.gov/

History and Mission

The Landsat program was inspired by the Apollo Moon Mission, which photographed the Earth from space for the first time. This pushed Dr. Paul Lowman to suggest the idea of terrain photography experiments for upcoming missions including the last two Mercury missions, Gemini missions, and Apollo 7 and 9. In 1965 Willian Pecora the director of U.S. Geological Survey (USGS) pursued the idea, presenting it to the Department of Interior (DOI) suggesting the development of a satellite program to collect information on natural resources using remote sensing techniques. The program left the ground in 1966 helped along by Dr. Lowman's results with orbital photography. The program started to encounter opposition on many levels. The first was that of its own government who believed it to be fiscally irresponsible. The Department of Defence argued on the behalf their reconnaissance missions believing that such a civilian project could compromise their secrecy. Geopolitical problems also emerged concentrating on the issues involved in photographing foreign countries without permission and their paranoia of U.S. examination of their natural resources, causing the name change from Earth Resource and Technology Satellite (ERTS) to Landsat. NASA began to build the satellite but again in confrontation with financial issues and sensor disagreements, it was put on hold. It was in 1970 when the project was restarted and on July 23, 1972, two years later, Landsat 1 truly took off the ground, marking the first Earth-observing satellite with the specific mission of monitoring the planet's surface. "The ERTS spacecraft represent the first step in merging space and remote-sensing technologies into a system for inventorying and managing the Earth's resources." (Higer, Coker, Cordes 1976: 160) The satellite was mounted with an RCA camera named the Return Beam Vidicon and a Multispectral Scanner by General Electric. The latter was installed to be more experimental but as soon as the data flowed back it was considered to be invaluable. It was able to collect data from four spectral bands including green, red, and two infrared. The satellite lasted untill 1978 and took 300,000 images.

Landsat 1 was followed up by many other satellites upgrading through time to evolve into Landsat 7, the Enhanced Thematic Mapper Plus (ETM+) which was launched in 1999 (Figure: 6). ETM+ was a new addition to this satellite revising the Thematic Mapper from Landsat 4 and 5. The ETM+ allows for some new enhanced images worth discussing. It contains a panchromatic band with 15m spatial resolution, an on-board full aperture with 5% absolute radiometric calibration, a thermal IR channel with 60m spatial resolution, and an on-board data recorder. The new addition to the satellite allows it to be accurately calibrated.

The mission of Landsat has continued from its start in 1972 to today, taking multispectral images of the Earth’s surface. With Landsat 7 they have been able to develop their mission to build a periodically refreshed global collection of sunlight and cloudfree images. The satellite is able to cover one quarter of the Earth‘s landmass in 16 days. This allows for many important studies to be conducted involving aspects of image comparison over time. This also means that the data base is so large that most images which are needed will be already available.



(Figure 6: History of Landsat.)

Technical Specs: (Chart: 4):

Spectral Range: Visible: blue, green, and red light. Nonvisible: near infrared, mid-infrared, and thermal-infrared.

Resolution: Changes with band selection; multispectral bands are 30m while thermal bands are 60m, while panchromatic band has a resolution of 15m.

Costs: (Chart: 5):

The images supplied by Landsat are based on "Cost of Fulfilling User Requests", known as the COFUR price. The benefits from following this method are that it not only reduces costs for commercial data sold but allows access to academic institutions. Another cost effective way to acquire these images is from previously archived images which are donated by the original purchaser and are afterwards heavily discounted.

ASTER

http://asterweb.jpl.nasa.gov/

History and Mission:

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a tool attached to the Terra satellite. This satellite was launched in 1999 as part of NASA's Earth Observing System in a cooperative effort with Japan's Ministry of

Economy Trade and Industry (METI) and also Japan's Earth Remote Sensing Data Analysis Center. The goals of this satellite were to examine new research methods of examining the Earth's land, oceans, air, ice and life function as a comprehensive environmental system. ASTER was just one of five instruments installed on the Terra platform. Others are CERES, which is designed to measure the solar-reflection and Earth emitted radiation from the atmosphere in an attempt to learn about the roles of clouds and their involvement in the energy cycle of the global climate and MISR whose role is to provide information on the Earth's climate such as the partitioning of energy and carbon between the ground and atmosphere, also studying the impact of different particles and clouds in our atmosphere on the climate. This is accomplished with nine widely spaced cameras which can use stereoscopic techniques to construct 3-D models and estimate the amount of sunlight reflected. MODIS is another component on the Terra platform integrated with another satellite called Aqua. It is designed to view the entire Earth in two days using an impressive 36 spectral bands to improve the understanding of the processes taking place on the land, oceans, and low atmosphere, in hopes of developing prediction models for environmental changes on a global level. MOPITT is the final device that is on the Terra satellite. This Canadian designed instrument is used to measure pollution in the atmosphere. With these instruments on the Terra platform, one can definitely see why this satellite is considered part of the Earth Observing System and how each instrument will help pursue the objectives given to this satellite.

Technical Specs (Chart: 6):

ASTER is broken down into three subsystems.

1. VNIR: This operates two telescope assemblages one looking backwards with one near-IR wavelength and one looking nadir, pointing directly down at 90°, with three bands. This allows for three spectral bands to simultaneously view the same area to 15m resolution.
2. SWIR: Uses a single aspheric refracting telescope which allows for the viewing of six spectral bands in the near-IR region with a resolution of 30m. This device is also used to correct errors with in elevation data used in systems such as DEM's.
3. TIR: Operating five spectral bands in the thermal infrared region to 90m resolution with one fixed nadir facing telescope.

Costs:

The data can be obtained in four different levels depending on individual needs. All ASTER products can be purchased at the relatively cheap price of $80 for each scene no matter the level.

QuickBird

http://www.digitalglobe.com/about/quickbird.html

Mission:

QuickBird is designed and run by DigitalGlobe to provide accurate, high resolution imagery, supplying panchromatic and multispectral images, applicable for mapping and land management. The first QuickBird satellite was launched in 2000 while the second was in 2001. The benefits of using the QuickBird satellite is that one can acquire sub-meter resolution, GEOLocate for accuracy refinement, and an image footprint 2-10 times the size of the regular high-resolution satellites. The satellite is capable of collecting seventy-five million square kilometres of imagery a year. This provides a large collection of archived images to select from.

Technological Specs (Chart: 7):

There are four technological advancements that are seen on the QuickBird satellite that make it the useful tool that it is.

1. High resolution sensors, this is important for creating maps, image analysis, and detecting changes in the landscape.
2. Image accuracy, this is facilitated by the GEOLocate feature that allows for the creation of maps without the use of ground control. It is especially useful in remote locations. This is accomplished through the standardization of locality strings, and compiling data such as distance, compass directions, and geographic identifiers to help verify and correct the error in the accuracy readings. This limits the accuracy to within twenty three meters.
3. The size of the images is 16.5 km in width. This allows for the images to come as a single image of 16.5 x 16.5 km., or a strip of 16.5 x 165 km.
4. The high quality of the image is important to the interpretation, supported by unique acquisition methods, for example, high quality images despite low light levels. This is sustained by the telescope on board QuickBird allowing for larger field of vision, high signal noise ratio, and high contrast.

Costs:

The pricing for these images are between twenty and eighty dollars a square kilometre depending on the level of processing and map accuracy.

SRTM

http://www2.jpl.nasa.gov/srtm/index.html

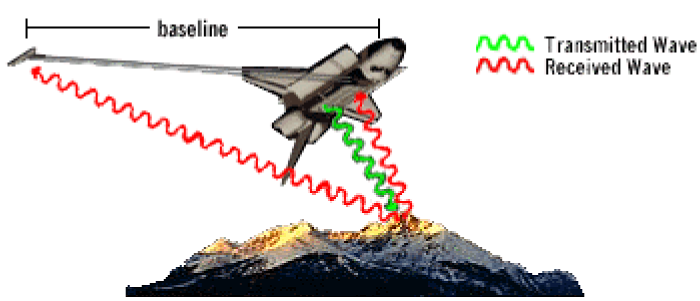
Mission:

The SRTM, Shuttle Radar Topography Mission, is a program run by the National Geospatial-Intelligence Agency (NGA), and the National Aeronautics and Space Administration (NASA). The SRTM project is part of a large shuttle called the

Endeavour. The goals set out for this mission are to produce digital topographic data that covers eighty percent of the Earth's land surface, more specifically the land between the latitudes 60˚ north and 56˚ south. This project is useful to many different disciplines and is best suited for studies on the shape and height of the land.

Technical specs:

The data acquisition is accomplished through the use of radar interferometry, which analyses two images of slightly different locations for the surface elevation or surface change (Fig: 7). This is accomplished by one radar antenna on the shuttle and another attached to an extended arm which reaches sixty meters out. These antennae record in different bands. One is C-band while the other is X-band. Whereas C-Band creates DEM's the X-band creates higher resolution DEM's but not without the help of the C-band. The shuttle allows for data point location every arc, 30 meters on a latitude/longitude grid with vertical accuracy to be within sixteen meters with ninety percent confidence. There are many potential uses for this apparatus that are being explored.



(Figure 7: SRTM showing interferometry)

Costs (Chart: 8):

There are two types of images that can be acquired from SRTM. Both of these are based on of the previously discussed cost-to–produce fee. The first is unfinished which is the first version of the data and the second type is finished. The finished images are also called version 2 these are images that have undergone substantial editing by the NGA to show well defined water bodies and coastlines.

SPOT

http://www.spot.com/html/SICORP/_401_.php

Mission and History:

This is another satellite that is designed for the observation of natural resources and human activity to monitor, study, manage, and forecast them. The satellite was designed to have objective and reliable pictures, and with the over 10 million achieved images each one showing a surface area of 3,600 km. sq., it practically covers the Earth's surface many times over, accomplishing the mission's directives. It has proven to be cost effective, easy to use, and it also has the ability to directly integrate, extract, and combine information for many programs that can perform image processing.

Technical Specs:

The satellites follow general resolution and spectral ranges characterized in chart 9. The images, which will come as complete scenes, are 60km long and 60 to 80 km wide and the extracts of the images are shown in chart 10. The images themselves can be purchased at three different levels, 1A, 1B, 2A.

SPOT satellite can revisit the same area on the Earth each day. This feature is important because it can be used to monitor quick changes in vast or small sized areas. The images that SPOT creates have many uses which include, geometric image processing, photo interpreting, thematic studies, and creating DEMs.

These are not the only applications and to emphasise this SPOT has created a few programs to help supply individual needs of its consumers. The first SPOTview, has both multispectral and panchromatic images which present the information in the form of product underlays. These underlays can be used with GIS and other map-making systems. The images will have accuracy of 30m or better depending on the ground control points and DEMs available during pre-processing, reaching up to 15m with higher level images from DEMs. This program comes in different standards; SPOTview basic and plus. It is oriented for updating digital maps, mapping regions with poor or non-existent maps, mapping land use, natural resources, and new thermatic layers.

SPOTimage, another program, was developed to help with studying geological structures, designing and engineering mobile phone networks, and preparing missions and navigation files for weapon systems. This program is known for its accuracy without ground control points.

Reference 3D is a geocoded database covering the whole world. This was started in 2002 when the new SPOT satellite was launched collecting 7million km. sq. a year of images. The size of these images varies depending on the distance from equator but the images at equator are at a 1"x 1" scale correlating to 111km x 111km.This data base is comprised of three information layers.

1. SPOT DEM: This digital elevation mapper gathers a uniform grid of elements encoded with terrain elevation data. These are acquired from the SPOT HRS stereo pairs. The accuracy is summed up by the absolute plainmetric of 15m at 90% confidence without ground control points. The absolute altimetric accuracy is 10m at 90% confidence for a slope greater then 20% and up to

30m at 90% confidence for high elevation areas. The data can be framed to whatever size is needed for the individual project, being sold by the square kilometre.

2. HRS: These are orthorectified images from the DEM which provides them with an absolute altimetric accuracy of 16m at 90%.
3. Quality and traceability data: This provides data references and footprints for the DEMs and orthoimages. It also describes the processing for DEM and allows for accurate estimates.

VEGETATION is a convenient name for the multispectral instrument on the Spot 4 and Spot 5 satellites designed to provide daily coverage of the Earth at a constant resolution of 1 km for the field of view of 2400 km, while monitoring the continental biosphere; vegetation coverage, agricultural production, and deforestation issues. This sensor covers four spectral bands, three of which are identical to the sensors on SPOT HRIVR and HGR, allowing for interactive studies between the satellites. The fourth band, blue wavelength, is used for atmospheric corrections for the other bands. This product comes in three types of images. The first is primary products that are extracted from a single image segment. The second sends daily or ten day mosaic of images of the same area. The third type is called vegetation indices which are calculated from daily or ten-day syntheses.

FORMOSAT-2 allows for relatively broad coverage in extremely fine detail, two meter panchromatic images and eight meter multispectral images. It is mainly used for military operations and surveillance. The multispectral range has four bands; blue, green, red, and near-infrared. A blue band is created by combining red and green bands which is useful for distinguishing between bare earth and vegetation through the creation of natural-colour composites. Other features that FORMOSAT-2 boasts of are the ease of mapping in unfavourable weather conditions, reliable repeat imagery, and monitoring fast-changing situations on a daily basis. This is the only high resolution satellite to do so.

Costs:

The prices are broken into two categories, images from. SPOT 1-4 range from $1,200 to $1,900, SPOT 5 ranges from $3,375 to $10,125, depending on resolution and spectral mode. These images can be purchased in different sizes, a full image covers 60x60km and can be purchase in half, quarters, and eighths, decreasing value.

Conclusion

Archaeologists armed with this knowledge should be able to make an informed decision on what satellite would complement their research the best. The information presented is for the most part from the satellites official websites and provided handbooks. If individuals want more in-depth information the best way is to contact the individual companies (Chart 11).

Case Studies

The major goal of this paper is to present the readers with the many applications of remote sensing. This section consists of case studies, important because it provides the ideas of how remote sensing can be applied in the field, what problems the archaeologists ran into, and how they were overcome. Each case uses satellite imagery in different ways and in different contexts. Archaeologists such as Sarah O'Hara and her work in Syria using the Corona satellite and Derrold W. Holcomb in the Gobi desert of Mongolia will be examined. The purpose of this chapter will be to open the reader's mind to the endless possibilities of remote sensing and the possibilities of satellite imagery.

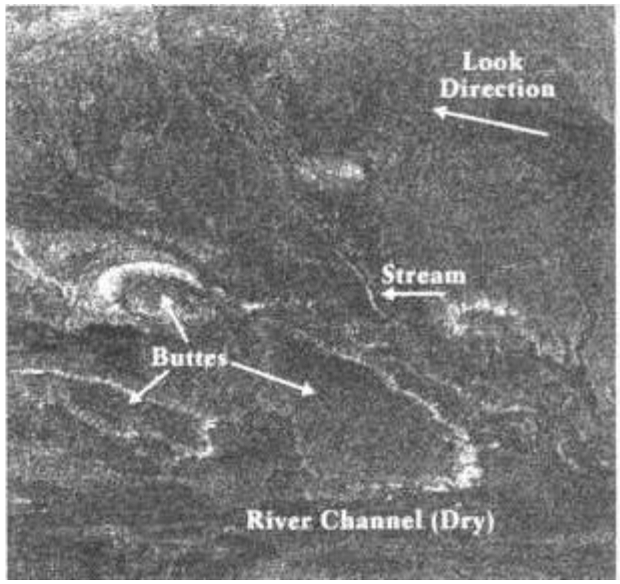
Imaging Radar and Archaeological Survey: An Example from the Gobi Desert of Southern Mongolia.

Donald W. Holcomb.

The first article by Derrold W. Holcomb, is examining the Gobi Desert in Southern Mongolia. This article assesses the usefulness of remote sensing in semiarid environments. Holcomb decided to use RADASAT, a satellite with multispectral and near infrared capabilities. Two major components in this article will be examined; techniques and methods used and the second, appropriateness of using remote sensing and the results.

Two methods and techniques discussed in Holcomb's work are of interest. The first involves image interpretation. Foreshortening and shadowing involves the angle in which the satellite image was taken. This produced shadows over the landscape which either hide or emphasise features. The images were taken at an angle of 10-59° off nadir (Holcomb 2001: 132). Illumination for these images was produced by radar pulses which made them highly directional in nature; this is referred to as the 'look direction'. Without the radar pulse, the images have widespread and very dark shadows (Holcomb 2001: 132). This also caused problems with the mosaicing of the images. The final interpretation issue that Holcomb ran into was speckling noise; irregular occurrence of artificial bright and dark pixels due to returning radar waves to the satellite (Holcomb 2001:134). To compensate for this one can apply speckle reduction algorithms which reduce the resolution which in turn reduce the speckle noise; therefore a balance will need to be found.

The mosaicing process involved the collaboration of the satellite images to create a large image. This is done with a number of features to help make the mosaic accurate. The first step was to select an initial geo-referenced image with a good distribution of recognizable ground features that can be used to tie up the overlap. Then the next step was to align the images with the ground control points. The third step is more complicated in which the images are converted from flat images to convex ones due to the Earth's curvature. Holcomb expresses three important aspects in this process, the first is that the more tie points the more accurate the maps will be. A tie point can be anything, roads, river junctions, or buildings (Fig: 8) (Holcomb 2001: 131). There are programs such as ERDAS which Holcomb used to help with the tie points and overlapping of maps. The second is that the accuracy is dependent on the accuracy of the latitude and longitude of the initial image. The third aspect is that Radarsat images are done under the assumption of a mean sea level. This causes a 2 meter offset for every meter of elevation. This was overcome by using ortho-correction software which is based on true radar orbit and an imaging model (Holcomb 2001: 133). The data was corrected and geo coded when it was registered into a DEM, this can also be done using GPS ground points.



(Figure 8: Showing the ease of tie points.)

There are lots of reasons why using satellite images are appropriate for this region. The area of study takes place in the vast area of central Asia and it has semi arid to arid soils. The geography shows that to do ground surveys would cost much in time and money, due to the lack of roads, harsh environment, and would even put the surveyors in considerable risk (Holcomb 2001: 131). By using the satellite images they were able to map large areas in a short amount of time. This allowed for more precise and accurate intensive ground surveys to be conducted with efficiency. Being able to map vast amounts of the area at once offered unique perspectives to Holcomb which would not have been available if conducting ground surveys. Holcomb was able to observe the geographical layout of the land. Maps were studied for regional sequences and large scale phenomena such as the human effect on the landscape. This was especially pronounced in conjunction with water. Due to the semi arid landscape, water was an important asset to the inhabitants. Consequently the waterways would have a strong influence on them. They in turn would have manipulated the waterways. The imagery was able to present water access to arable land and alluvial fans being distributed over time and space which allowed for defining the paleoclimatic patterns and gradients (Holcomb 2001: 136).The desert preserved evidence of how people manipulated the environment for the appropriation of water and in turn distribution of vegetation cover, for example the alterations in the stream paths seen from the sediment deposits and micro-climatic conditions (Holcomb 2001:136). Other human effects on the landscape became visible on these images such as transportation routes and communication lines. The authors found that with the presentation of this evidence they were able to accurately locate sites to survey. They also found that by having hardcopies of these maps in the field the survey teams could navigate the terrain much quicker and more easily.

Holcomb produced a very important and useful article which has been used here to exemplify the possibilities of remote sensing in large arid environments, showing how cost effective, efficient, and accurate a tool it can be.

Corona Remotely-Sensed Imagery in Dryland Archaeology: The Islamic City of al-Raqqa, Syria.

Challis, Keith., Priestnall, Gary., Gardner, Adam., Henderson, Julian., Sarah, O'Hara.

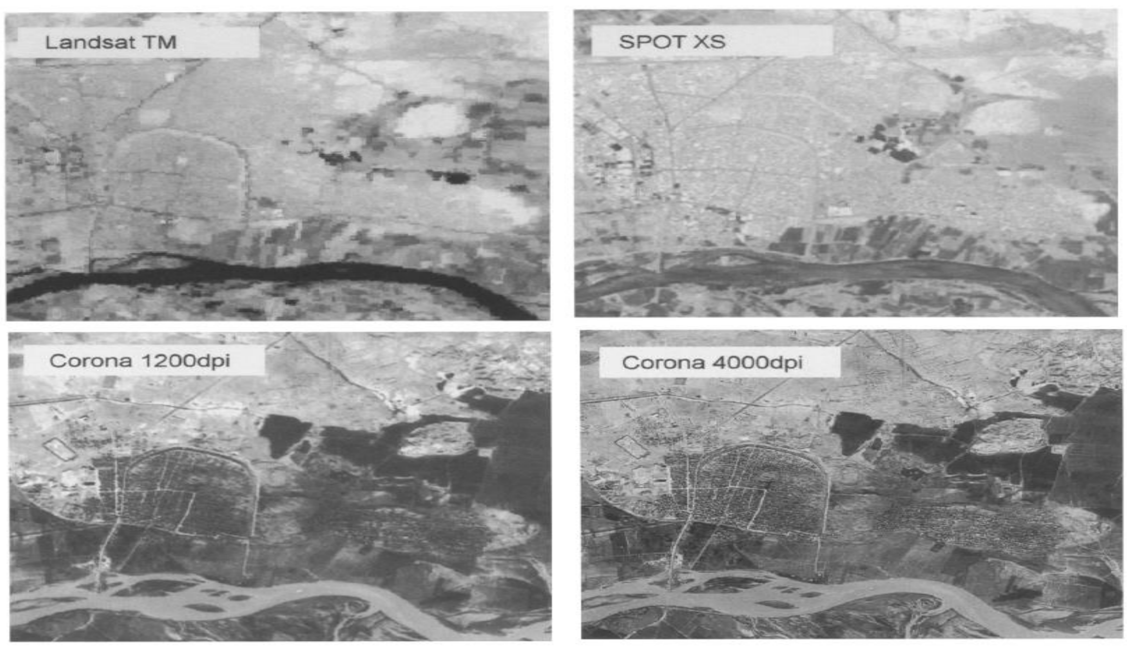
The next case study involves a study of the city of al-Raqqa in north central Syria close to the Euphrates River and the tributary the Balikh. The time period stretches from the Neolithic through to the Byzantine periods. This study started in 2000 in an attempt to reconstruct the spatial organization of the industrial complex and to assess human-environment interactions, looking explicitly at pollution and resource use (O'Hara et. al 2000: 140). Remote sensing falls into this by topographic maps, mapping environments, cultural features, and the identification of potential excavations. The principal feature was an early Islamic city called al-Raqqa, which was defined by horse shoe shaped city walls.

The satellite used most in this research was Corona. This satellite was particularly useful because its data base was relatively old and prior to much of the modern construction. This is important because like these images there have been many occasions when satellite images become declassified after many years. These are great for archaeologists because these depict the landscape before a lot of modern developments. The images in this project came form a collection 860,000 Corona photographs from 1960 and 1972, declassified in 1995 by the United States (O'Hara et. al 2000: 139). The expansion is noted over time, broken down into three phases. In 1924, the modern settlement covered 36ha of the 2937ha of archaeological remains. This was seen through aerial photography. By 1967, Corona images show the expansion to 339ha and finally in 1987 a SPOT image shows the expansion up to 1592ha. This is still occurring with the expansion of Modern al-Raqqa.

The images were from a high resolution KH-4B camera system which included two panoramic cameras. Similar to Holcomb's situation these images had to be rectified and had many of the same issues such as the curvature of the earth, and optics of the camera (Holcomb 2001: 131). They encountered a unique problem with the panoramic images because of their high levels of distortion but this was overcome with computer enhancements before being instituted in a GIS system (O'Hara et. al 2000: 139).

Interestingly, in this article a comparison of satellite imagery exists. A picture (Fig: 9) compares Landsat TM, SPOT XS, and two types of Corona images. One can clearly see the differences in resolution (O'Hara et. al 200: 143). It is stated that while Corona provides a cheap way to map broad areas it is not comparable to the new satellites of QuickBird and IKONOS with higher resolutions and repeatable area coverage, but there are some disadvantages such as price and limited areas covered by them (Chart: 12).

The conclusion of this article states that Corona imagery provided a low cost solution to mapping the cultural landscape and the hinterland of al-Raqqa. Corona works best in arid areas of land with little vegetation so that the ground details can be seen clearly (O'Hara 2000: 151). In comparison with aerial photography it becomes the cheaper more efficient substitute.



(Figure 9: Satellite comparison)

Conclusion

In this paper the ultimate goal is to inform readers about the possibilities that remote sensing provides for survey projects and the satellite imagery resources available to archaeologists. In this section an introduction to satellite imagery was presented over three chapters. The first was an introduction to satellite imagery, discussing the basic principles behind satellite imagery, different terminology, physical mechanisms used to produce these images giving an overall understanding of the subject. The second chapter presented the resources available by discussing the individual satellites, their missions, technical details, and costs. The third chapter examined two case studies to provide information about genuine archaeological projects that utilized remote sensing techniques, presenting the benefits and issues encountered in their work. This section illustrate the usefulness of remote sensing while the providing some of the essential information needed to proceed with the application of satellite imagery in archaeological projects.

Case Study: Antikythera

Antikythera is a small island between Crete and the Pellopenese, located off the coast of Kythera, a larger island (Fig: 10, Map of Antikythera). This study is conducted by Dr. James Conolly and Dr. Andy Bevan and is important on several levels. The location has been very important for trade, over the decades and is known for it piratical history, and continuous occupation starting as far back as the Neolithic. The second important aspect of this island is the size, 21 square kilometres; this small size allows for the complete surveying in two sessions and in-depth gridding of promising locations of the island over a three year period.

This section on remote sensing deals with three areas of study, mapping cultural features, vegetation analysis, and visibility analysis. Each section will include an introduction, method, and discussion. Each of these will be conducted through the use of satellite imagery and be compared to hard data collected from the work conducted on the island.

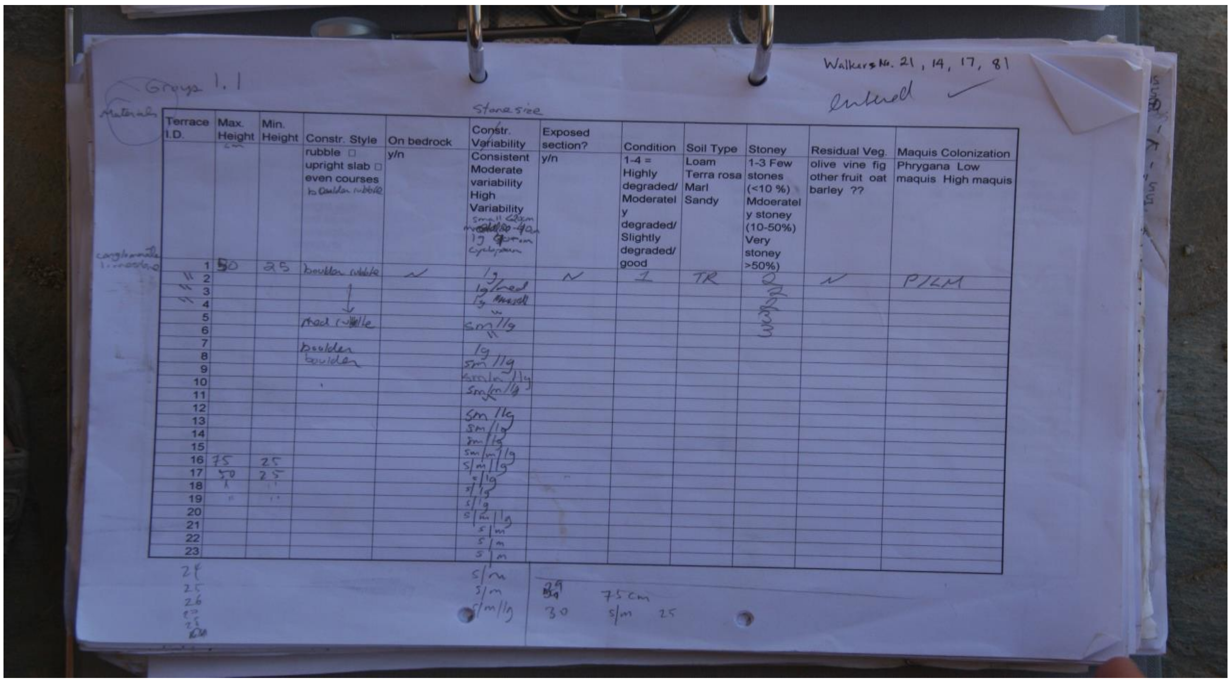
Cultural Features

Introduction

This section will deal with the use of satellite imagery and mapping of cultural features. Cultural features include any human manipulation of the environment. Therefore it includes a wide variety of different subjects. By examining satellite images one can successfully identify these features. While this may sound like a simple process there are main complications to be considered.

To accurately describe the process, complications, and benefits, an example of the terrace mapping project conducted on Antikythera will be examined. This study involves the mapping of terrace systems on the southern side of the island. Through the personal experience of participating in this project a first hand account can be recorded, providing intimate details.

The study involved the intensive mapping of terrace systems on Antikythera. This island is ideal for such a unique study. The size allows for mapping the entire island, over two consecutive field sessions. The initial development of this project has been extremely interesting**.** Since there was little previous work had been done on this topic before, allowing for the creation of new methods which over time went through a great deal of reconsideration due to practicality and time constraints. This also allowed for a great deal of freedom in techniques and innovation. The project initially started with very in-depth inspection of each individual terrace. This included the examination of height, highest and lowest portions, construction style, stone size, soil consistency, indigenous plant life, and deterioration. This proved to be very time consuming and a slow process. We modified the method and grouped together specific terrace systems based on area and similarities, then completed an over reaching description of the group, satisfying previous qualities. This proved to be a much faster method and resulted in fairly accurate information for terraces, for within each group they tended to follow similar characteristics. The method was further modified when the time restrictions increased. The terraces were no longer grouped together, deciding that the groups can be identified quickly and efficiently at a later date. The terrace project was conducted on the simple means of mapping each terrace thereby further increasing the efficiency.



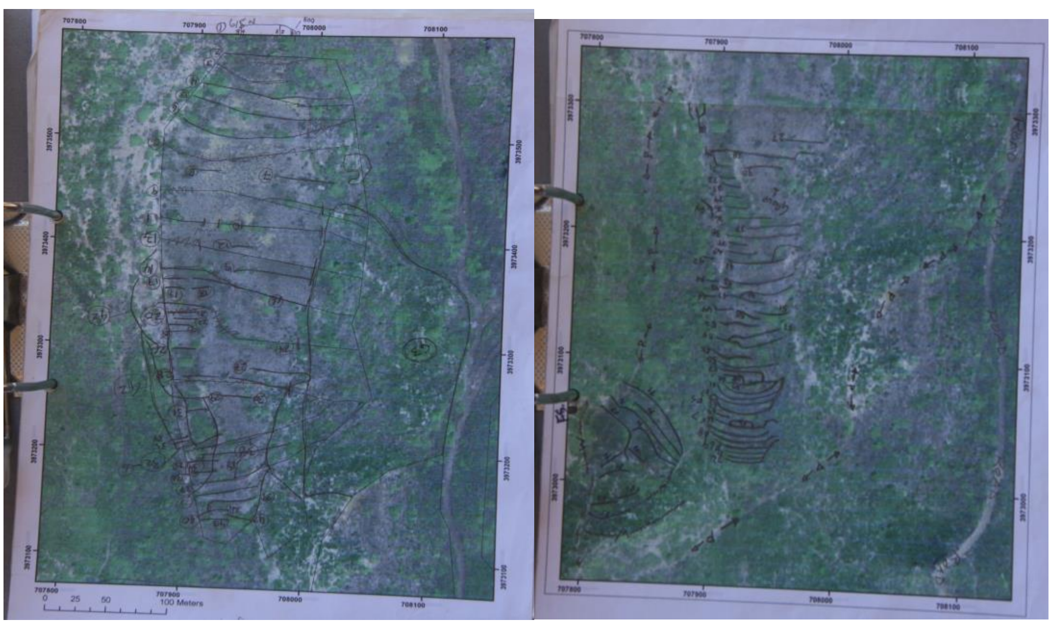
(Fig: 11 Terrace record form)

Method

Satellite images were acquired from QuickBird at a variety of different resolutions. The methods involved in mapping are very simple in description but become more complicated when actually instituted in the field. One needs to examine the image and decide to what extent they perceive a terrace group, thereby creating an imaginary boundary (Fig: 12). The next step is to start at the bottom of the group, lowest portion and work up, drawing in the terraces. This is important for when looking down the slope the terraces are less distinguishable. Numbering and physically flagging the terraces is recommended in order to reduce confusion. To map terraces is like drawing a puzzle, if one leaves or stops the work it is incredibly hard to find the place where they left off.

(Figure: 12 Field map of North East terraces, example of grouped systems)

The variation in satellite resolution is very important for the efficiency and accuracy of mapping. The terraces were drawn directly onto the printed images. In the larger systems clearly seen on the images the lower resolution maps were more useful allowing for a larger picture of the system, though not allowing the precision needed for the smaller terraces. To acquire the precision for the smaller terraces the higher resolution maps were needed allowing for the smaller terraces to become more visible, also ground control points were more visible (Fig: 13). As previously mentioned ground control points were any identifiable feature, mainly consisting of larger bushes, bare bedrock, and open soil. They are the most noticeable on the maps. Ground control points are used to locate the position of the terraces, especially the ends. Another important device which proved to be useful in the placement of the terraces was global positioning system (GPS). Mappers were equipped with a handheld GPS to help record the location and position themselves. This was useful for larger terraces but when precise locations were needed, it proved somewhat ineffective. There is a ten meter variable that the GPS worked on meaning that it always had the possibility of reading ten meters off on top of the believed accuracy of the unit. Although more precise equipment is available such as total stations which dramatically increase the accuracy, these devices do not come without penalties; cost, power limitations, and weight all play a factor. Even with these inaccuracies mapping with a GPS is extremely beneficial. One can however operate without it. Many projects work without GPS and are based on calculations from different equipment such as a theodolite, which in many ways can prove to be more precise and versatile.



(Figure: 13 Field map of Death Valley, increased resolution)

The satellite images can give the impression of being able to map the terraces without entering the field. This is incorrect for there are many discrepancies that are encountered when ‘ground truthing’. Certain natural features give the impression of terraces such as bedrock, bare soil, and vegetation (Figure: 14, Image of bedrock on North East outcrop originally thought to be terraces). While there should be an effort invested in examining and creating a legend for these features, they vary greatly for each individual situation, making it a very tricky procedure. This relates to many smaller or more discrete cultural features. Recent work in this field shows very promising results especially with the manipulation of satellite imagery and improvements in technologies as seen in the paper.

Conclusion

The end product of a two week field session consisted of a complete mapping of all the terraces of the southern portion of the island with an in-depth analysis of selected systems in addition to the grouping of many different systems. In doing so this has created a unique data set which can facilitate terrace studies both on the island and as a comparative reference. The method developed will allow for the efficient mapping of the remainder of the island in the upcoming 2007 field season.

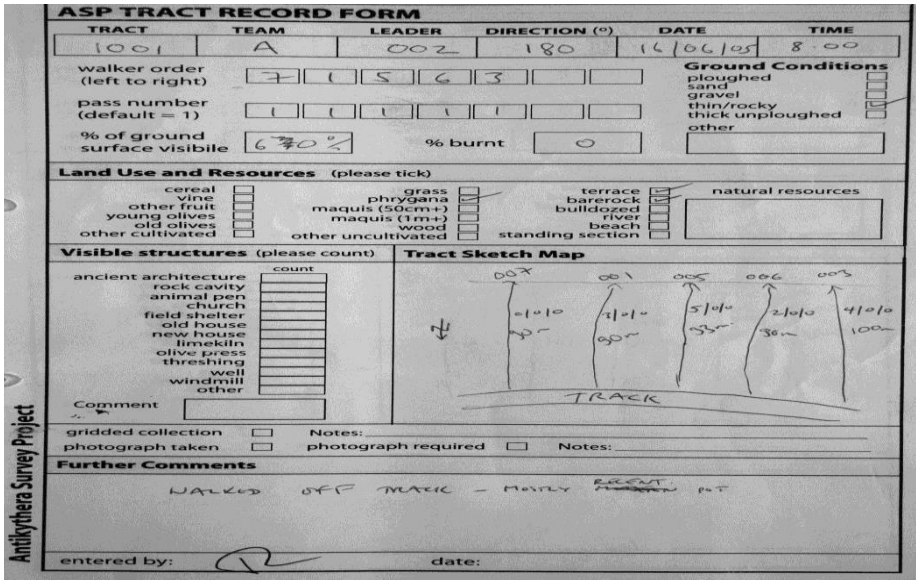
Case Study: Visibility, Vegetation, and Artifact Density

Archaeological survey projects have been using satellite imagery as a crutch for conducting work in difficult areas, to speed up the process, to assess the areas, and a variety of other useful purposes. Opposed to this trend this case study will use satellite imagery in a more quantitative case study of the island of Antikythera. This study will be an analysis of the work conducted by field surveyors, examining the visibility of the earth's surface and comparing it to the work conducted through remote sensing. This will be accomplished by the analysis of QuickBird imagery using computer based viewing programs to complete visibility and vegetation analysis, examining predominantly the red and near-infrared bands which are more conclusive for the analysis of vegetation and visibility. Using the computer based program Idrisis three types of maps will be created; NDVI, supervised, and unsupervised. The purpose of this study will be to describe the methods of conducting the study and to examine results in an attempt to assess the biases that vegetation can have upon the artifact recover rates.

Visibility

Introduction

The term visibility seems very simple at first but has a dramatic effect on all aspects of field surveying. What visibility means in the archaeological sense is a percentage of ground that an individual track walker can see. This has an implication on the statistical application of artifact densities; the more visible the ground, the more likely the field walker is to find artifacts. The use of remote sensing in this field is developing into an extremely important resource. Examining satellite images from QuickBird the potential level of visibility can be assessed. To show how this is accomplished, a study of Antikythera will be conducted. The unique nature of the island and project is beneficial for such a study due to the completeness of the survey and the track record forms. These forms record information such as vegetation type, number of artifacts, and visibility, providing a wealth of comparative data (Fig: 14). The visibility will be assessed through remote sensing and then compared to these records, allowing for the assessment of the accuracy of remote sensed visibility and its potential in surface analysis. This will be presented in two sections, image manipulation and discussion.



ASP TRACT RECORD FORM

TRACT	TEAM	LEADER	DIRECTION (°)	DATE	TIME
1001	A	002	180	16/06/05	8.00

walker order (left to right) 7 1 5 6 3

pass number (default = 1) 1 1 1 1 1

% of ground surface visibile 6 70 %

% burnt 0

Ground Conditions: ploughed, sand, gravel, thin/rocky, thick unploughed, other

Land Use and Resources (please tick)

cereal, vine, other fruit, young olives, old olives, other cultivated

grass, phrygana, maquis (50cm+), maquis (1m+), wood, other uncultivated

terrace, barerock, bulldozed, river, beach, standing section

natural resources

Visible structures (please count)

count: ancient architecture, rock cavity, animal pen, church, field shelter, old house, new house, limekiln, olive press, threshing, well, windmill, other

Tract Sketch Map

007 001 005 006 003

TRACK

Comment

gridded collection — Notes:

photograph taken — photograph required — Notes:

Further Comments

WALKED OFF TRACK – MOSTLY RECENT POT

entered by: — date:

Antikythera Survey Project

(Figure 14: Tract Record Form)

Methods

The collection of data from QuickBird images are inputted into a viewing program that has the capabilities to manipulate them, in this case IDRISI. There are four basic images that depict different wavelengths, blue, green, red, and near-infrared. There are many ways in which these maps can be changed and manipulated to informatively present the information. There are three steps needed to accomplish a visibility analysis: stretching, Normalized Difference Vegetation Index (NDVI), and classification.

Stretching

Stretching is the first step. Each of the four images project its wavelengths in a constricted state, meaning that they are restricted in terms of the size of wavelengths on the electromagnetic spectrum (Eastman 2001: 29). This can be resolved by stretching the maximum and minimum values expanding to reach a full band range of 0-255, thereby giving more depth to the images. (Conolly, Lake 2006: 146). Once this is accomplished the images are ready for manipulation.

NDVI

Normalized Difference Vegetation Index (NDVI) was developed to identify vegetation areas and their conditions. NDVI works through a mathematical expression[3] that creates a new map. This is done to overcome the problem of solar zenith angles interfering with the satellite images (Eastman 2001:55). The satellite images used in this study are Raster files in byte form; therefore they contain a numerical data base, similar to the numerical matrix used by computers except instead of 0's and 1's it ranges from 0 to 255 bytes (Eastman 2001: 46). These numbers are distributed over a grid; each band has its own grid of numbers. The concept of NDVI is to distinguish the intensity of vegetation. The wavelengths in the equation are chosen because of their individual characteristics. Near-infrared is sensitive to the solar radiation scattered by leaf vegetation, radiation over 700 nanometres equating to nearly half of the solar radiation (Eastman 2001: 32). This causes the plant vegetation to appear very bright. The red wavelength is used to compensate for this overemphasis; it shows visible wavelengths as very bright, opposite to NIR. The final product of inputting these two contrasting wavelengths is an image that contains ratios of reflectance, -1 to 1. Values describing the level of reflectance are assigned to each pixel and expressed in different colours. Colours are assigned to the different wavelengths but are variable depending on user's preference; they can also be adjusted to start displaying at certain levels. This allows for an analysis of surface coverage through the reflectance of green biomass from one area to another (Fig: 5, IDRISI: NDVI image) (Eastman 2001: 92).

Classification

The use of remote sensing to analyse vegetation provides important data on the vegetation cover and density which is very useful on many levels. The first level is with

[3] NDVI= (NIR-RED) / (NIR+RED). NIR: Near-Infrared Red wavelength. RED: red wavelength.

the physical survey, by assessing the vegetation that field walkers have to tackle during the day. The second is visibility used to assess tract records and the potential biases that vegetation can have on the number of surface finds. Thirdly, a vegetation analysis presents a framework of the area's environmental situation. There are two ways in which raster files can be assessed; supervised and unsupervised. These relate to the classification of vegetation and its grouping. As discussed, satellite images are based on the reflectance of energy from the earth's surface. The changes in wavelengths over the spectral range for each different aspect of the earth including the vegetation are called spectral signatures (Eastman 2001: 40). The receivers in satellites interpret the data and assign it numerical values which are used by software programs such as ArcView or IDRIS to present the information in coloured maps.

The idea of supervised and unsupervised involves the identification and classification of the spectral signatures. The programs used to examine these maps are capable of distinguishing between the spectral signatures on the map. With supervised classification one needs to select specific training locations in which the spectral range is classified as a spectral signature and identified as a specific surface feature. This process can be referred to as signature analysis (Eastman 2001: 40). When a suite of surface features is assessed, this can be applied to the entire map. There are two further classification methods within the supervised technique. Hard classification is the most common, applying the identification to the signature with the highest probability. In soft classification, areas are identified and attached with the probability of specific vegetation, for example 75% chance it is maize with a 15% chance it being bare soil. The soft classification will then be re-examined and a decision will be made on what it represents.

Unsupervised classification works similar to supervised. The difference is that the identification of the spectral signatures does not happen until after they are grouped. This technique is referred to as cluster analysis. In this study both supervised and unsupervised classifications will be used and then evaluated for usefulness. Potential reasons for using the two in terms of archaeological surveys will be examined.

Unsupervised

Unsupervised classification can be accomplished in a few different modules. The cluster module was used in this study due to the accuracy and level of classifications provided. There are two steps in creating an unsupervised image. First is the development of a composite image, the combination of the three primary bands; blue, green, red. This provides a base which the module can examine in order to differentiate groups. A cluster module creates a number of groups in which it can divide the signatures into (Fig: 6, IDRISI: Cluster image). This approach allows the option to choose the number of groups but does the analysis without knowledge of class composition or what it may represent(Conolly, Lake 2006: 147).

Supervised

First, it must be decided what suites of surface features are needed for the analysis. Bare soil, bare rock, water, and vegetation are the categories for this study. Water was included so that it can be set to values below 0, therefore exempting it from the study. To create classification categories requires prior knowledge of surface features in the area of study (Conolly, Lake 2006: 148).

The process of classifying happens in three steps. First one creates a training group in which each training site is assigned a spectral signature (Conollly, Lake 2006:

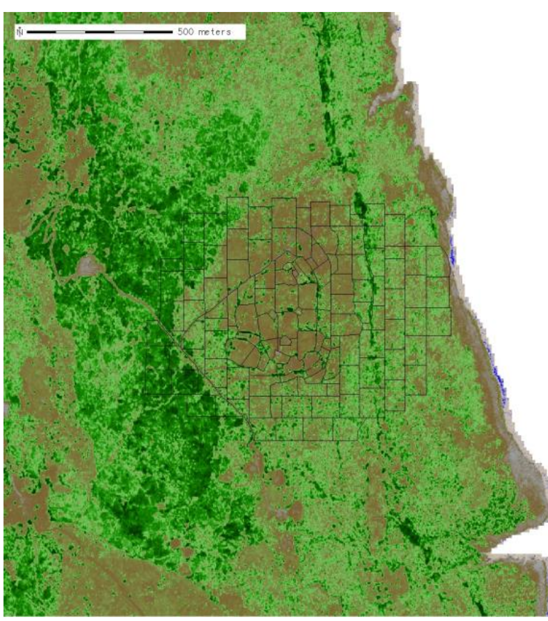
148). This is accomplished by digitizing the map; selecting certain aspects of the landscape that is descriptive of the individual feature. This then is applied to a map that classifies the total area into each of the categories, allowing for a quick identification of the regions. There are several modules that perform this, each one with its own specific technique in deciphering between spectral ranges of the signatures and the responses from the surface. All modules provided by IDRISI were examined and two modules proved most effective in this study; MAXLIKE and MINDIST. MINDIST stands for the Minimum Distance to Mean, this is the procedure it uses to classify signature files (Fig: 7 IDRISI: MINDIST image) (Eastman 2001: 30). Pixels are assigned signatures based on the closest mean reflectance of each band, allowing for band-space distance to be normalized (Eastman 2001: 8). Using the standardized distance makes this module more sensitive to poorly defined training sites. MAXLIKE uses maximum likelihood, meaning that the classifications of signatures are processed with a probability of density function (Fig: 8, IDRISI: MAXLIKE image) (Eastman 2001: 30). Assignation is based on the comparison of posterior probability of each pixel and signature, based on the Bayes' Theorum[4] (Eastman 2001: 91). The end result of these modules is a map that is similar to unsupervised; having a set of signature groups referring to surface features and the ability to examine the reflectance ratio anywhere on the map except these are predescribed groups.

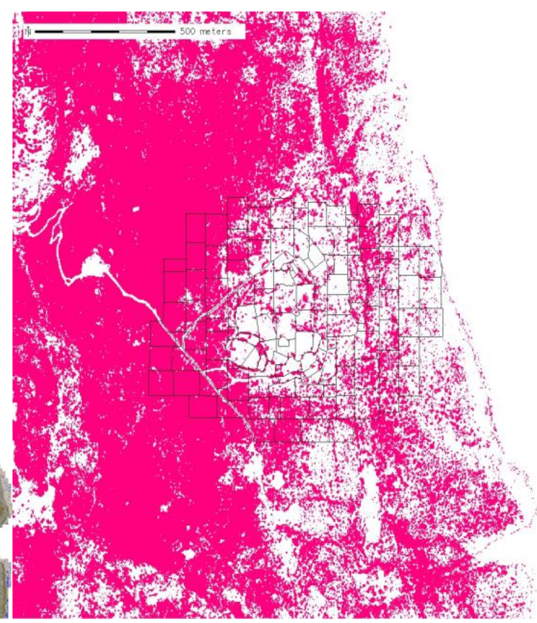
Compilation of Data

The NDVI and unsupervised MAXLIKE maps created in IDRISI were imported into the GRASS program, a GIS program. GRASS contained a complete compilation of

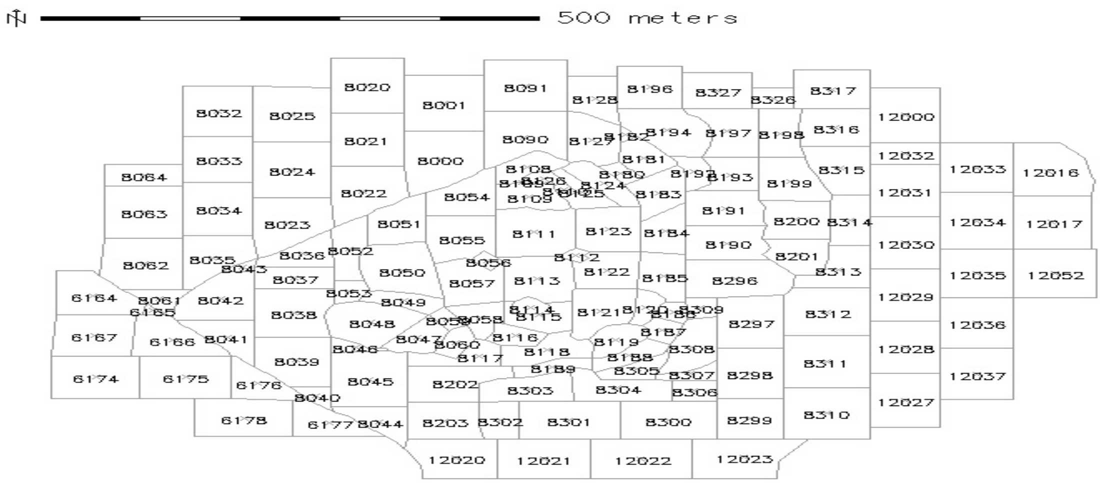
[4] Bayes' Theorum: Prior knowledge incorporated as a prior probability of each signature class applicable to all pixels.

the tract record data from the field. This data was designed into maps of tracts that were completed over the entire island. Within each tract it contained the specific data for that individual tract. These maps were further modified by overlaying them with tract units. Also the MAXLIKE map was modified to show only the vegetation category (Fig: 15). Two other maps were also created; the first one containing the tract units and assigned number (Fig: 16), the second with tract units and sherd counts (Fig: 17). The data within Grass was created into a spread sheet in Excel, holding information on the tract record forms; tract number, visibility, sherds, other, distance, and density. A small section of the island was chosen on the Eastern portion of the island containing 139 individual tracts. This area was named Bulgaria based on similar physical characteristics. This Excel sheet was then modified by adding the statistical data that the NDVI and MAXLIKE map contained for Bulgaria, including the number, max, min, mean, range, standard deviation, variance, and coefficient of variance of their recorded vegetation analysis and NDVI values. With this data in hand the analysis could then begin in earnest.

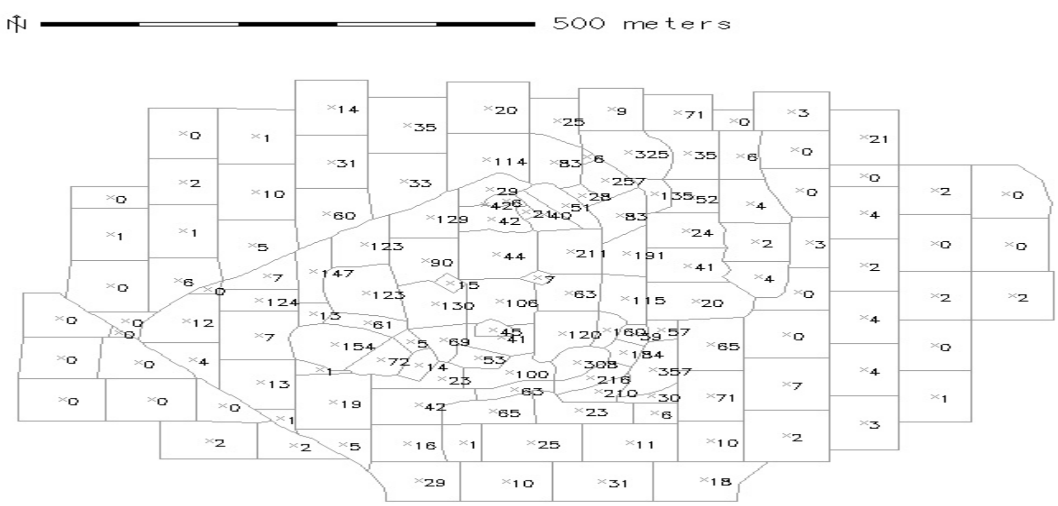




(Figure 15: Bulgaria with tract units, Left NDVI, Right MAXLIKE Vegetation)



(Figure 16: Tract numbers, Bulgaria)



(Figure 17: Sherd Count, Bulgaria)

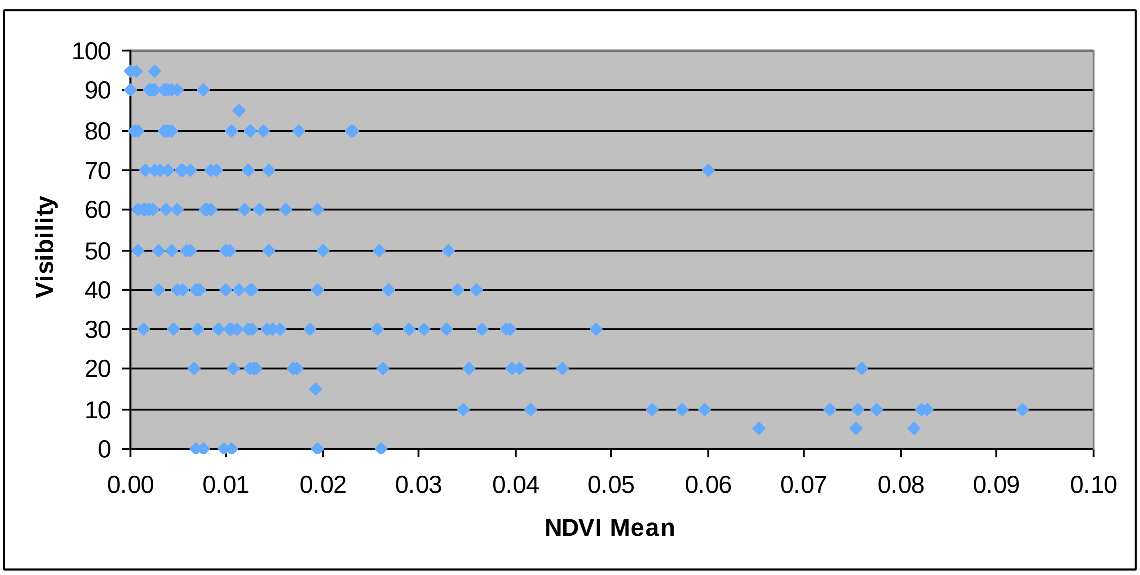
Excel

The Excel spread sheet provided the data to perform a number of statistical tests to find any correlation between a number of factors. The statistical tool utilized in this study was linear regression; this is used to test different dependent variables which are believed to be linearly related to another set of variables. There are four tests being conducted to complete this analysis.

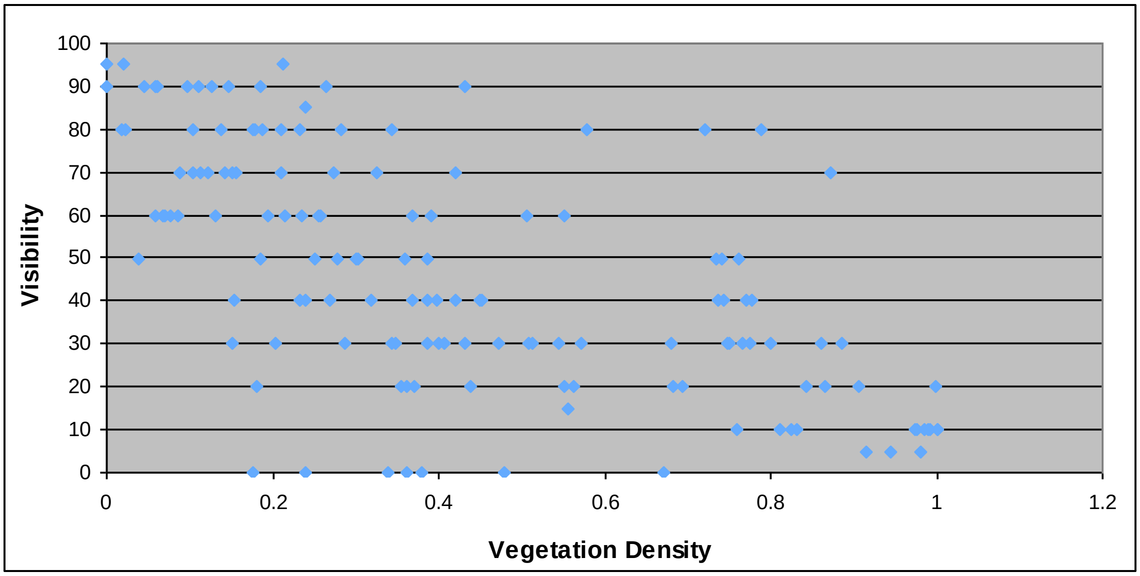
Analysis

Observed Visibility vs. NDVI and MAXLIKE

In this section the correlation between the observed visibilities in the field will be compared to the mean NDVI values and the Vegetation Density. Vegetation Density is derived from the Vegetation rating from the MAXLIKE image, divided by the NDVI value. The NDVI mean compared to the Visibility shows a fair measure of negative correlation (R: 0.631) (Fig: 18, Chart: 13).Visibility and Vegetation Density (Fig: 19, Chart 14) again shows negative correlation; this data has a looser correlation (R: 0.569) than figure five but instead of the high density of points at the lower vegetation readings it is consistent throughout the graph. In both graphs there are two groups of outliers, above and below the standard values. Through the analysis of these outlying groups, examining their numerical data and their NDVI and Vegetation image an explanation can be derived. There are four different factors which will be discussed to describe these anomalies, vegetation, tract size, time of year, and data analysis.



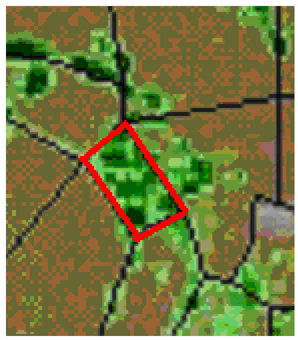
(Figure 18: NDVI Mean vs. Visibility)



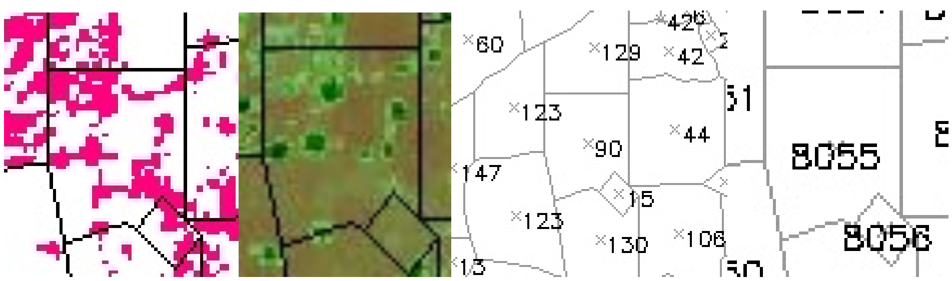
(Figure 19: Vegetation Density vs. Visibility)

Vegetation

The analysis of vegetation requires the examination of the outliers to discovery and discrepancies. There are tracts which exhibit zero as visibility and are presented with a variety of NDVI and Vegetation ratings. These can be explained by examining the vegetation and its possible effects during the data collection and processing. In the case of tract 8313 and 8183 there appears to be a gully running through the tract which is full of dense vegetation. Depending on the placement of walkers they could easily perceive the tract as zero visibility while the vegetation map will acknowledge the entire tract and rate it accordingly, with a marginal vegetation density. Another situation where vegetation can be considered an issue is tract 8059, recorded with the visibility of 70 and the NDVI mean of 0.06. This tract is seen in figure 20; appearing to be completely covered in vegetation. This could mean two things, first that the walkers were not affected by the vegetation. Either it was very short grass of some kind or they were able to go under it. In many cases there are juniper bushes that have very dense outsides while on the inside it is hollow. Tract 8055, appears to be a very visible area which is supported by the numerical data but is still rated as zero visibility by the walkers (Fig: 21). Upon examination one would believe that this is due to communication error. Though the data surrounding shows a trail of low artifact densities that are on the Eastern tracts but also there are high visibility counts around the tract. This low visibility may be due to a non-vegetation aspect or vegetation that exhibits low chlorophyll counts such as dead plant matter. This situation would require ground truthing to reveal the true nature.



(Figure 20: NDVI, Tract 8059)



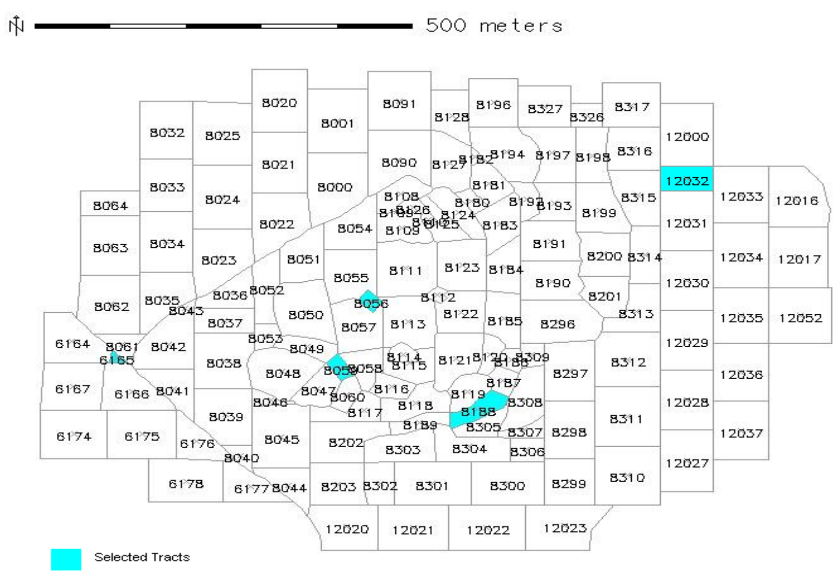
(Figure 21: Left to Right, Vegetation, NDVI, Sherd Count, Tracts)

Time of year

As discussed earlier the time of year in which the images were taken is very crucial to their interpretation and can have a dramatic effect on the results. Antikythera is subjected to very dry seasons in which much of the vegetation dies off or is in dormant the island was surveyed during. Other times of the year the area is more moist, in terms of a Mediterranean island therefore more hospitable for plant life.

Size

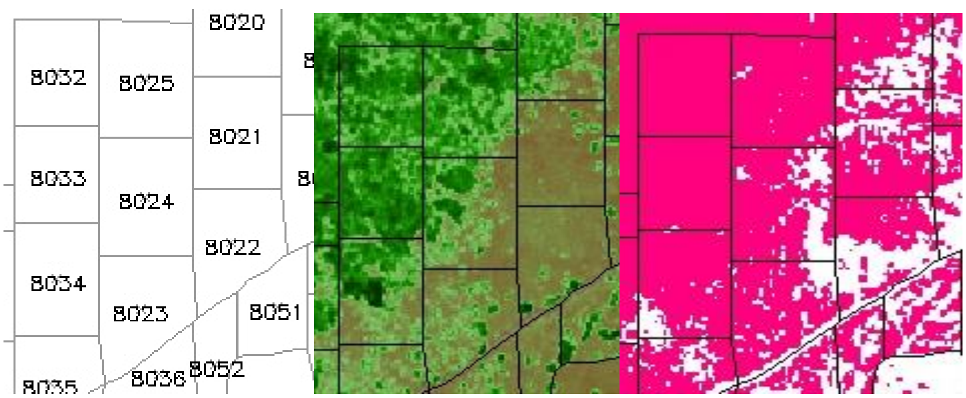
The size of the tracts appears to have affected the consistency of the visibility, there are four tracts that have small tract sizes (Fig: 22, Chart: 15). In this case they all consist of tracts under 300 m long. These discrepancies can be explained due to the resolution that the NDVI and Vegetation calculations are made from in comparison to the field walker who is not affected by the size of the tract. For example the computer based classification assigns vegetation values to every pixel group, 10m by 10m, while a field walker can get a feel for his tract and assign a more precise value. The method in which tracts are prescribed Vegetation and NDVI readings also needs to be examined. In some cases there may be a very intense reading of chlorophyll of only a small section of the tract. This would increase the NDVI and Vegetation reading while the visibility may only have been affected in one small area. This would be characterized by high readings in all aspects. There are other small tracts which do not appear to be affected in this way; this is due to both computer and human agreeing on a value.



(Figure 22: Tract map and small outliers; 8059, 8056, 6165,8188)

Data Analysis

This example requires a much more visual explanation (Fig: 23). Tracts under examination are 8021, 8022, 8023. When the Vegetation and NAVI images are compared the differences become immediately apparent. While the Vegetation image shows the majority of the area as covered the NDVI presents the opposite, appearing much more unobstructed**.** It appears as if the NDVI is more accurate when compared to the high accounts of tract visibility (Chart: 16). This can be explained by the more definitive method in which the Vegetation map assigns vegetation values, while the NDVI values are more flexible.



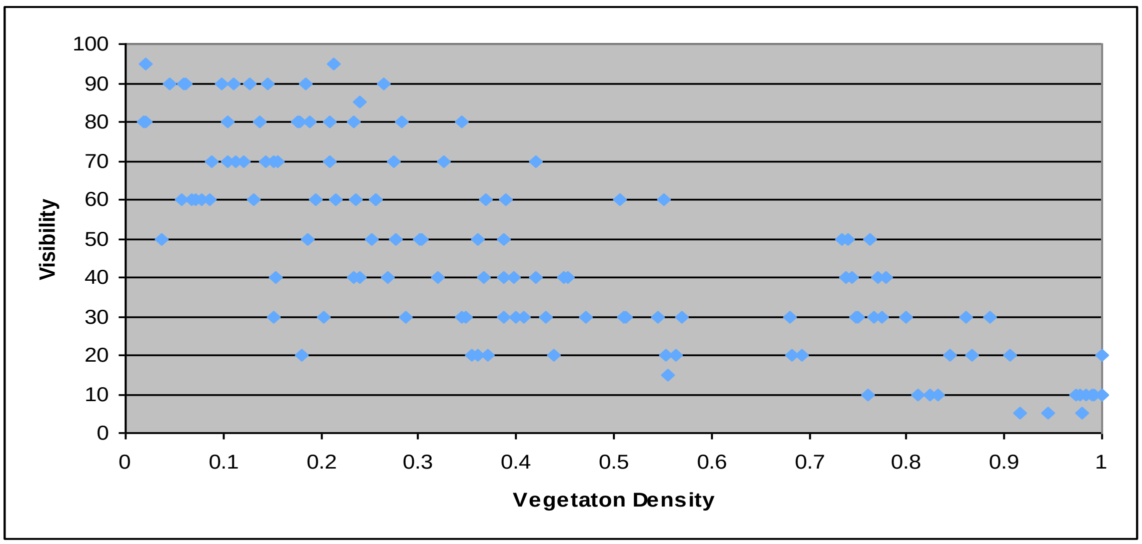
(Figure 23: Left to Right, Tract, NDVI, Vegetation)

The second aspect of consideration is the high density of points in the lower NDVI and upper visibility. As seen it appears to follow the same linear regression but appear very compact. This can be explained in two fashions, first it may represent the subjectivity of assigning visibility in the field or it may be that the NDVI readings do not provide enough range in the lower numbers.

When conducting a regression analysis it is important to examine the outliers so that they can be removed from the dataset. This will result in a more accurate correlation coefficient (Conolly, Lake 2006: 156). This procedure was conducted on both Vegetation and NDVI values, removing eight tracts from the NDVI and twelve from the Vegetation

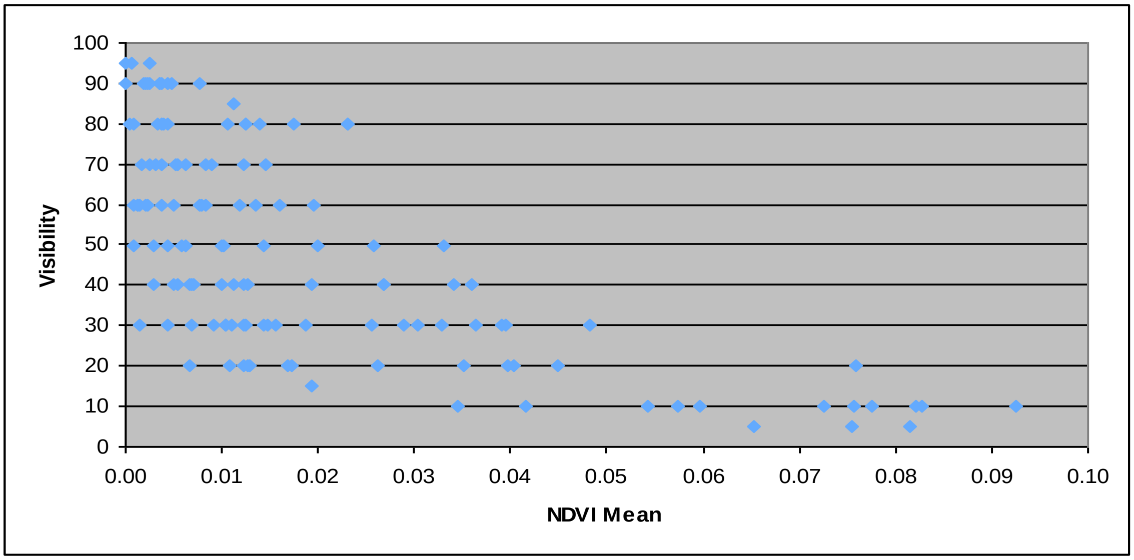
(Fig: 24, 25, Chart: 17, 18). As a result the correlation increased for both, most noticeable was the Vegetation correlation (R: 0.777) which surpassed the NDVI (R: 0.6689). This is due to the clustering of points in the lower values of the NDVI. While removing the outliers of the Vegetation data it still maintained its loose correlation but within a narrower procession. The necessity of completely understanding what the outliers represents is imperative in this process for if they are simply removed without consulting the potential explanation for their skewed reaction it could throw off the entire study and create an manufactured correlation.

Revised Visibility vs. Vegetation



(Figure 24: Revised Regression Analysis, Vegetation Density vs. Visibility)

Revised Visibility vs. NDVI



(Figure 25: Revised Regression Analysis, NDVI mean vs. Visibility)

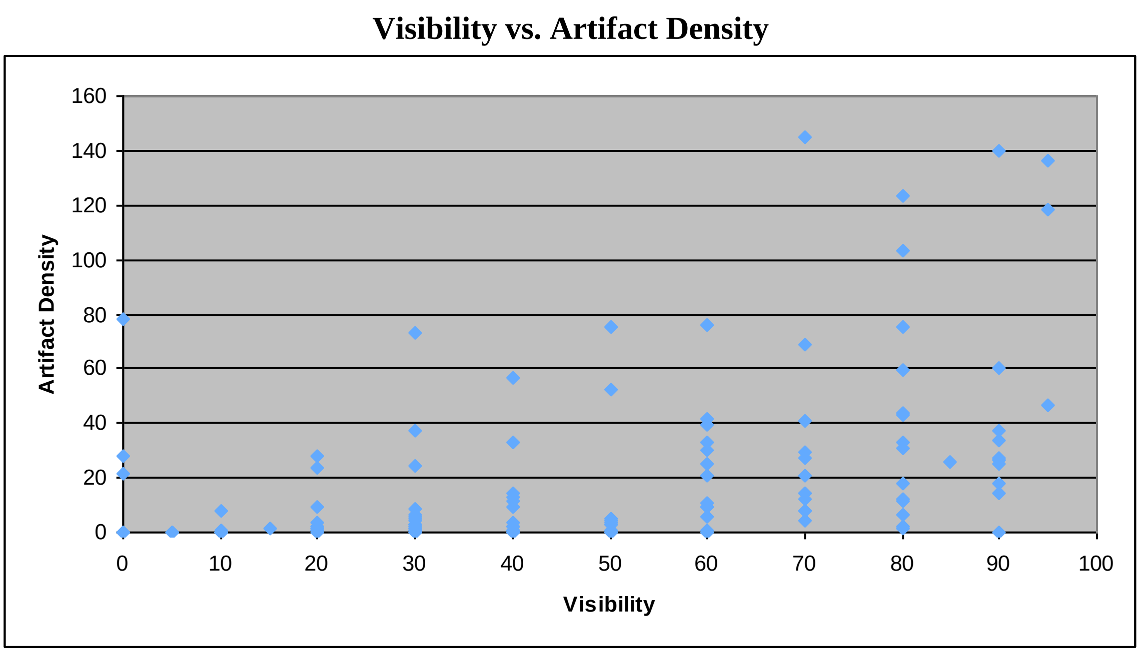
Conclusion

There is definite correlation in both cases of Vegetation and NDVI in comparison to the recorded visibility with Vegetation holding a stronger correlation. Through the analysis of the data and images in conjunction with personal experiences, a basic understanding of the biases and pitfalls of this comparison can be described. The importance of focusing on the outliers provides a selection of errors to examine. Their results can be anticipated and related to many of the issues expressed previously when exploring satellite capabilities. Issues such as resolution, vegetation, time of year, and subjectivity of analysis processes are apparent. Each one of these has relevance in this study and requires address before proceeding to any concrete conclusion on the effects of visibility on artifact recovery.

Artifact Density vs. NDVI and Vegetation

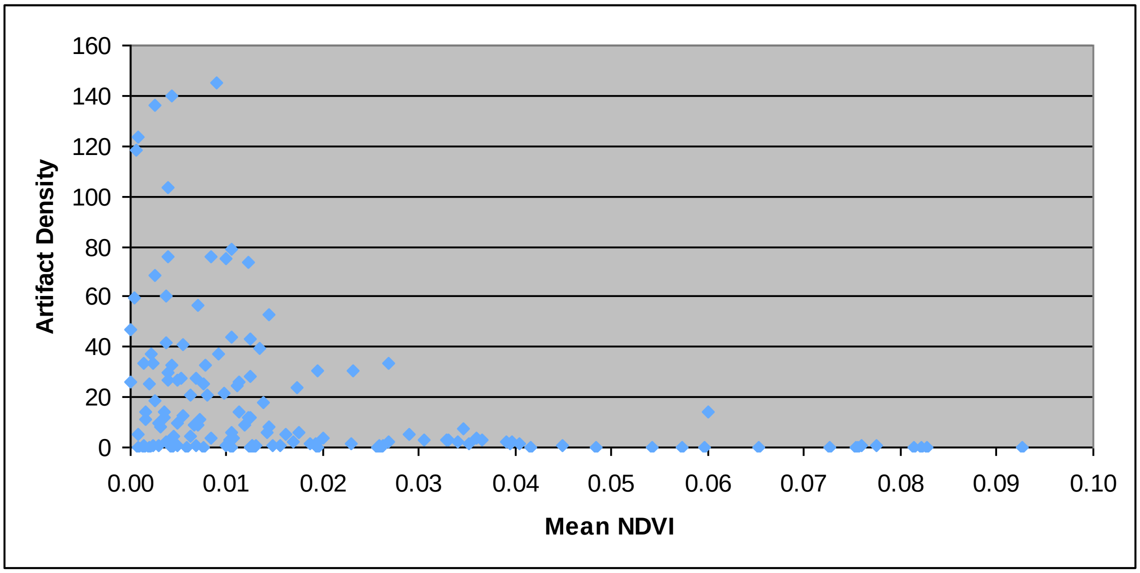
The rate of artifact recovery is heavily influenced by vegetation. This is an obvious statement but what is important about this is that with the developments in remote sensing has facilitated many new concepts of what data a map can contain. Being able to assign values to the degree of vegetation provides a base on which one can statistically examine the effect on recovery rates and recorded visibility (Bevan, Conolly 2004:127). There have been previous studies which examining artifact recovery and the possibility of assigning error correcting calculations. Howard, Bintliff, and Snodgrass conducted such a study described in *The Hidden Landscape of Prehistoric Greece*, which involved testing sampling strategies and statistical calculations to take into account a variety of variables that influenced the recovery and interpretation of prehistoric artifacts (Bintliff, Howard, and Snodgrass 2000). A more relevant examination was conducted by Andy Bevan and James Conolly on the Island of Kythera. This study proved to show little correlation between visibility and artefact recovery, concluding that due to the lack of interaction between the two it was unpredictable, and unusable until an examination of the relationships between artifact recovery and current vegetation levels is completed (Bevan, Conolly 2004:128) This is further supported by the similar lack of correlation between visibility and artifact density in this case study (R: 0.4736) (Fig: 26, Chart: 19). The lack of correlation between visibility and artifact density draws into question the validity of believing that the datasets with greater correlation with visibility, in this case Vegetation, is necessarily more accurate for such an analysis. Only through the examination of artifact density in comparison to both methods will this question be answered. Correlation is seen in the graphs depicting a clear line of find level and visibility regressing as the recovery rate decreases and visibility increases (Fig: 27, 28). The NDVI graph depicts the majority finds in the lower end, below 0.03. This graph has looser correlation (R: 0.3499) then the Vegetation graph (R: 0.47) (Chart: 17, 18). The

Vegetation graph depicts a wider range of visibility in which the find rate fluctuates, much more heteroscedasticity (Conolly, Lake 2006: 150). There are some important aspects to consider when examining these graphs. First no matter what the visibility is, there are not always sherds to be found. This explains the high density of sherds along the zero axes at varying degrees of visibility. As a result any removal of outliers will not be advantageous to this study. The graphs depict a distinct line which represents the level in which the vegetation level will not facilitate a higher rate of recovery. Below this line the recovery rate may vary depending on the actual amount of sherds available.



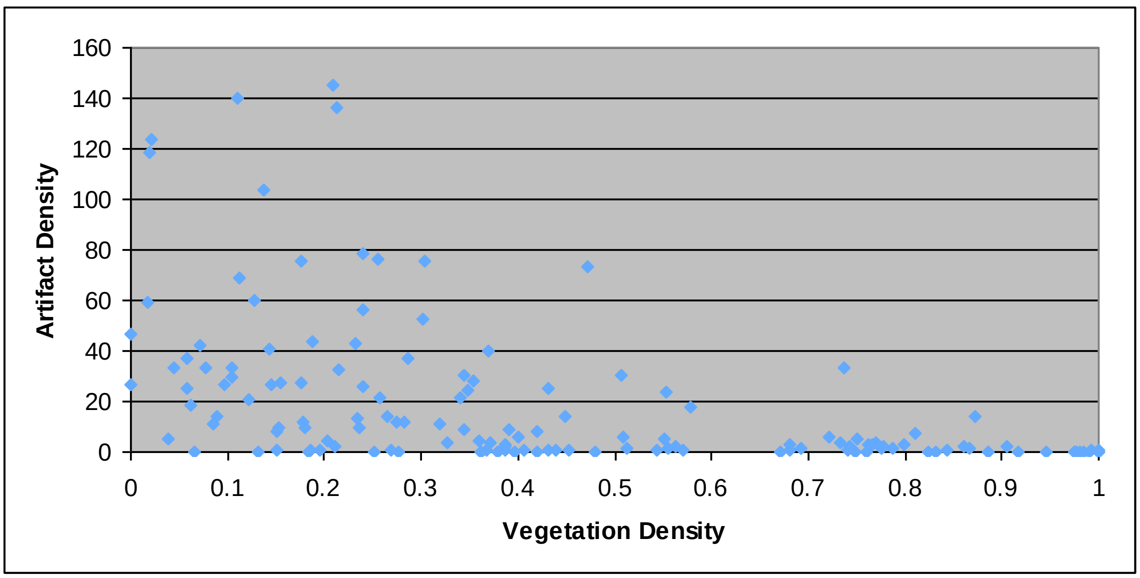
(Figure 26: Visibility vs. Artifact Density)

NDVI vs. Artifact Density



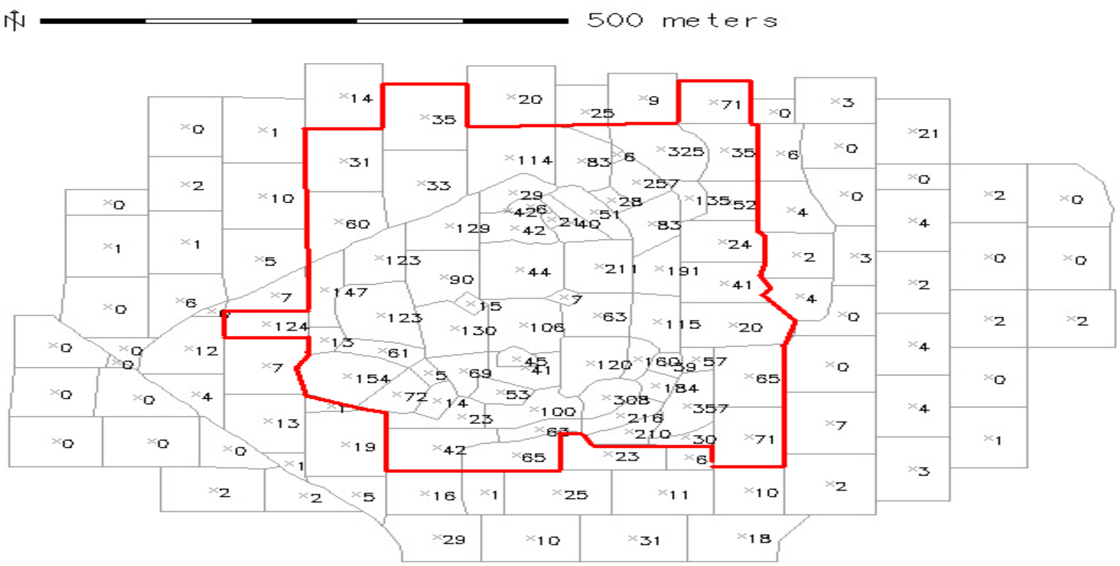
(Figure 27: Mean NDVI vs. Artifact Density)

Vegetation vs. Artifact Density

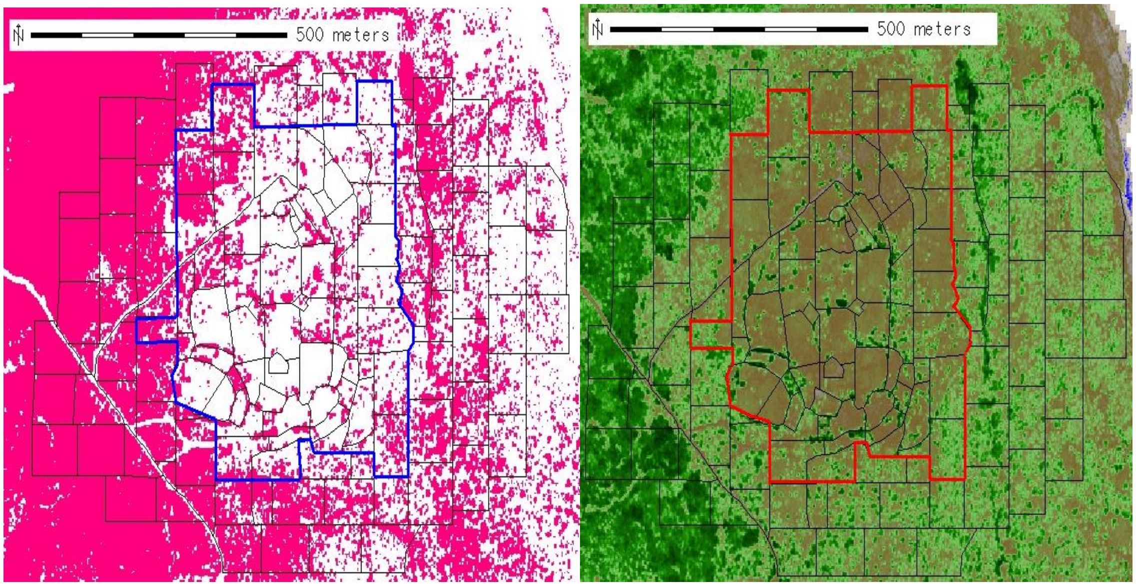


(Figure 28: vegetation density vs. Artifact density)

The description and extent of sites have always been an ongoing debate for archaeologists. Visibility values will help flesh out some of the controversy about the extent of a site. In this case study, there is a site in the middle of the study area. The site is characterized by a high degree of visibility and a large amount of sherds. What is interesting to consider is whether the sherd numbers or the vegetation defines the edges of the site. In figures 29 and 30, show the provisional site area is highlighted using the density of sherds dictating the edge of the site. This edge runs parallel to a marked decrease in visibility. This may be representative of two factors, first that the occupational phases of the site have affected the current level of vegetation making it more visible therefore making this assessment of site size accurate. The second reason is that the vegetation is dictating the site range and there may be more sherds throughout the high levels of vegetation that were missed, potentially missing large portions of the site.

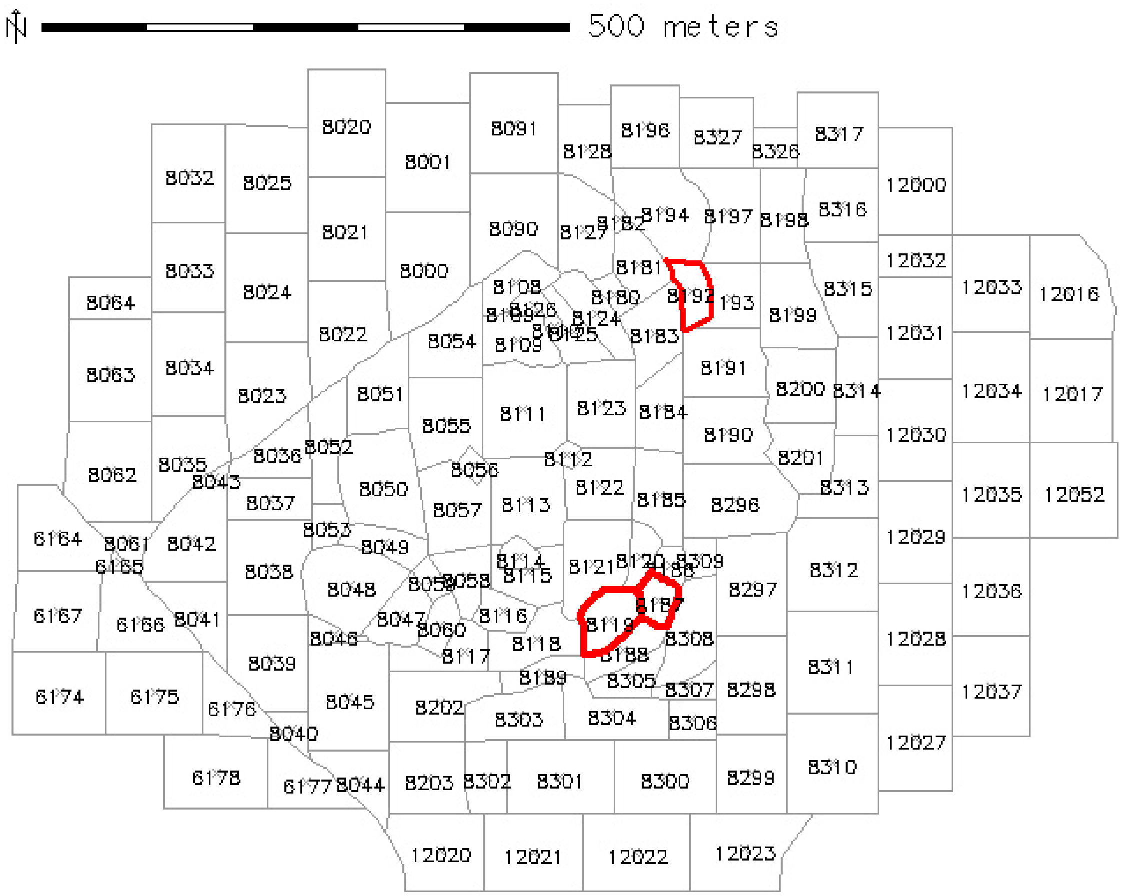


(Figure 29: Site Definition: Sherds)

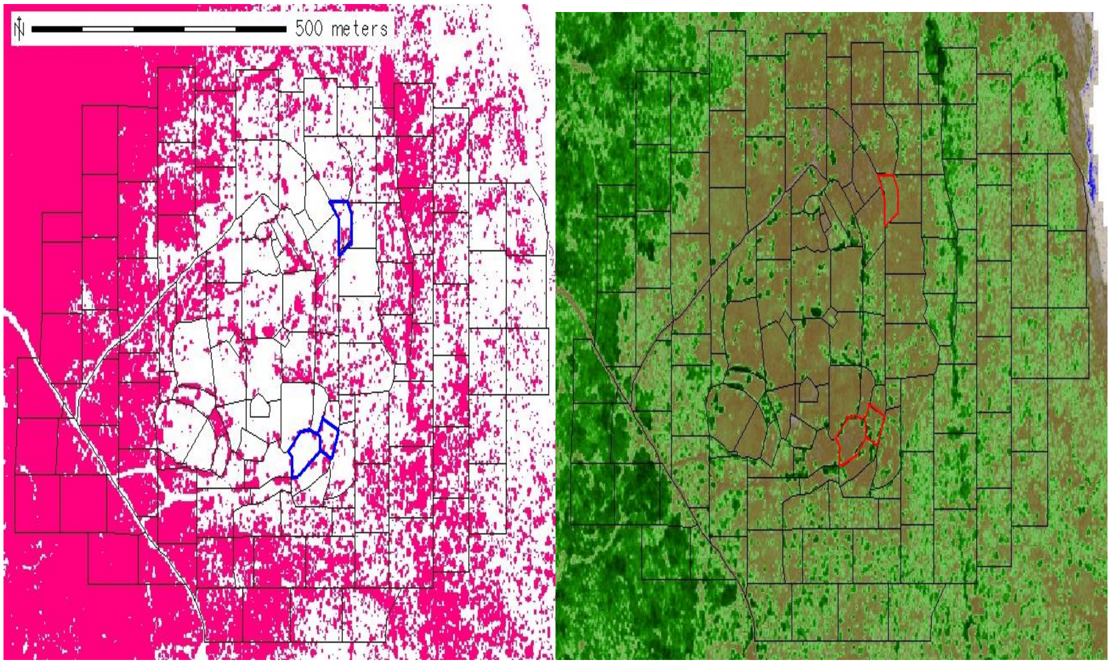


(Figure 30: Site Definition: Left, Vegetation. Right, NDVI.)

This study allows for the comparison of two styles of classification systems, NDVI and supervised Vegetation. Previously when examining the recorded visibility vs. the computational analysis of vegetation the NDVI was found to have much more tightly meshed values while the Vegetation graph presented the values in a more loose correlation. This trend is again visible in the recovery rate comparison. The NDVI presents the data with a lower level of vegetation rating while the Vegetation data is classified with higher scale of what certain levels of vegetation are. To express this difference three tracts were selected, 8119, 8187, and 8192, all with high levels of recovery (Fig: 31, 32. Chart: 22). Similar to the earlier discussion these tracts have a visible difference when examined with the Vegetation map showing a higher level of vegetation. The question is which method is best suited for this test? Through these examinations and personal experience of working in the area the NDVI readings would appear more accurate; unfortunately they are confined to a more constricted level. This may be worked out by stretching the range of the NDVI ratings in the lower levels. This warrants further examination in the future.



(Figure 31: Tracts with Defined sites; 8119, 8187, 8192)



(Figure 32: Defined tracts; 8119, 8187, 8192. Left, Vegetation. Right, NDVI)

Conclusion

The possibility of developing a mathematical equation to counteract the effect that vegetation has on recovery rates is a definite possibility. Through this case study a few further developments have been expressed. The size of area, its environmental variables, and surface morphology need to be considered before any definitive statements can be made about the effects of vegetation. In this case a smaller section of the island was chosen for it provided a solid base to express the effects of vegetation with a large variation in the degree of visibility. This is the proper approach because if a larger site was chosen it would have too many variables, vegetation, surface features, and sites to acquire or implement any accurate calculation. The second is in terms of the processes of developing the vegetation values. Through the examples one can see the differences between the unsupervised and supervised classification. In this study the supervised was found to be more precise (R: 0.7777) when compared to visibility. The supervised classification holds a lot of room for improvement. Through more precise and numerous training groups it could be developed into a more accurate process. Potentially these precise training groups could be developed based on different forms of vegetation and their individual effects on visibility. The unsupervised NDVI needs to be developed so that it can provide a broader range of low value definition; once this is completed it holds the potential to become an extremely powerful tool. When analysing maps to develop the right variables for such an equation it is absolutely imperative to have very descriptive records of the area focusing on aspects such as vegetation, cultural features, and surface morphology. This topic still requires a great deal of investigation and discussion in the future. This should be considered a very high priority for archaeologists due to the dramatic effect it holds on all survey projects, both past and present.

Appendix

Spectral Bands and Applications

Band #	Colour	Wavelength µm	Applications
1	Blue-Green	0.45-0.52	Max penetration of water (coastal mapping), soil/vegetation discrimination, forest classification (deciduous from coniferous), cultural feature identification.
2	Green	0.52-0.60	Vegetation discrimination and health monitoring, cultural feature identification.
3	Red	0.63-0.69	Plant species identification (chlorophyll absorption), cultural feature identification.
4	Reflected IR	0.76-0.90	Soil moisture monitoring, vegetation monitoring, water body mapping.
5	Reflected IR	1.55-1.75	Vegetation types, moisture content of soil and vegetation. Penetrates thin clouds.
6	Thermal IR	10.40-12.50	Night time images, surface temperature, vegetation stress monitoring, soil moisture monitoring, volcanic monitoring.
7	Reflected IR	2.08-2.35	Mineral/rock identification, vegetation moisture content.

(Chart 1: Bands, Colour, Wavelengths, Applications)

Satellite Systems and How They Work

System	Purpose	Mechanical Workings
Multispectral Scanner	Designed to capture images of varying resolutions and within a variety of spectral bands, depending on the individual satellite qualification. The images appear in black and white and then are assigned 'false colour' (Scollar: 197). This is an overlay of the primary colours, red, green, and blue, each colour assigned to an individual band, creating a false colour image. The importance of this is that it allows us, humans, to examine the relationships of the non-visual bands that our eyes cannot perceive.	Multiple images represented in different bands. Usually four mounted cameras recording, red, green, blue, and IR bands. Sometimes seen with one camera with four lenses. With newer systems 7 bands can be recorded.
Thermal IR Scanner	It detects and records the thermal radiation from the Earth.	Acquired from six bands of wavelengths less then 1µm.
Microwave Sensor	Acquires data about terrain and atmosphere.	This passive method does not emit energy, instead it senses the naturally emitted microwave radiation. The system is similar to thermal sensors except they use antenna instead of a photon detector.
Thematic Mapper ™	Developed in 1982, is a major improvement with greater spatial resolution, seven spectral bands with expanded visible and IR regions, the creation of a blue band, and the inclusion of thermal IR. The principal behind the acquisition is based on a cross-track scanner like the multispectral scanner, but has an oscillating mirror and arrays of 16 detectors which record the east and west bound sweeps. This is done to reduce the scan rate and provide longer dwell time to improve the radiometric accuracy (Sabins: 83).	There are a few different scanners available but they all work off the same basic principal. IR energy is radiated off the Earth onto a scan mirror then on a detector which converts the energy to an electrical output, varying in intensity due to terrain. The energy is cooled then projected onto a strip of recording tape (Sabins: 135).
Synthetic Aperture Radar (SAR)	The SAR synthetically increases the antenna's size or aperture to raise the resolution through the same pulse compression technique as adopted for range direction.	The SAR creates two dimensional images through range, a measure of line of sight, and azthium, perpendicular to range measurements. This requires the satellite to travel at high altitudes so that the calculations are more accurate.
Stereo pair	Allows for the illusion of depth and solidity.	Created from topographic images, using two cameras taking a picture of the same area from different viewpoint due to elevation.
Anaglyph	Creates a three dimensional image for the viewer.	To further utilize stereo pair images satellites reuse the old technology of anaglyph, covering of the left viewer with a red filter and the right with a blue filter.

Panchromatic Film	Been standard film type for years. Black and white film sensitive to all visible light and has a higher resolution then the multispectral images (Lillesand, Kiefer: 81).	Film usually used in a Kodak Wratten 12 or similar lens filter to eliminate the UV and blue wavelengths that are scattered by the atmosphere. Pixel equivalent to an area of 0.6m x 0.6m versus the mulispectral area of 2.4m x 2.4m. (Sabins: 39).
Infrared-sensitive film	Sensitive to UV, visible energy, and also near-IR energy (Lillesand, Kiefer: 81). Penetrates haze, uses maximum vegetation reflectance, totally absorbed by water therefore creating clear definition between land and water (Sabins: 42).	Used mostly with a Kodak Wratten 89D filter, allowing only reflected IR energy (0.7 to 0.9μm). This radiation is called photographic IR energy.
Interferometry	Created to counteract the atmospheric disturbance. Allows the collection of elevation data through its dual antenna system.	By analysis of two images of slightly different locations for the surface elevation, or surface change. This is accomplished by one radar antenna on the shuttle and another attached to an extended arm
Radar Backscatter and Radar Scatterometer	This nonimaging system measures the radar backscatter of terrain allowing for greater knowledge of the nature of the surface such as roughness, vegetation, and urbanization. These become more predominant because of their effect on the strength of the returning radar signal, but do not allow the creation of DEM's.	Using only one antenna from a radar interferometry system.

(Chart 2: Developments in sensor and satellite technology)

Image Interpretation Techniques

Viewing with B/W Radar Image Overlaid	A three dimensional perspective that is created with the radar backscatter and then overlaying it onto a topographic map. This style provides a unique map that depicts the nature of the surface along with its topography all at once. This can be further explored by adding the colour as height to the map.
Colour as Height	Uses two types of images, one that brightens as the strength of radar signal off the Earth increases, and the second is the colours which show elevation. When these are combined they allow for the changes in elevation to be reflected in changes in colour.
Radar Images with Colour Wrapped Fringes	Similar to colour as height, this combines two types of data; image brightness changing with strength of radar signal reflected off the surface and second, colours showing elevation. By following the sequences in colours, red through green then back to red, one can see the elevation differences. This is similar to the way contour lines work on a topographic map.
Shaded Relief	Computer generated light which illuminates the elevation to develop patterns of light and shadows. This helps show subtle features on flatter terrain. Colour as height can also be used with this shaded relief application.
Overlaying images	Using a topographic images from a satellite such as SRTM and then overlay this with an image Landsat, or SPOT which can have the multispectral ranges.
Contour Maps	Created with SRTM images that show the landforms of the surface. The contour lines follow areas of constant elevation and become more tightly spaced on steep slopes while widely spaced on flat surfaces.

(Chart 3: Developments in image manipulation.)

Landsat: Bands and Resolution

Band #	Spatial Range (Microns)	Ground Resolution (m)
1	.45-.515	30
2	.525-.605	30
3	.63-.69	30
4	.75-.90	30
5	1.55-1.75	30
6	10.4-12.5	60
7	2.09-2.35	30
Pan	.52-.9	15

(Chart 4: Landsat; bands, spectral range, resolution)

Landsat Pricing

Product Type	Price	Availability
Level 0R Single Scene	$475.00	General Public
Level 0R Multi-Scene (10 scene maximum)	$475.00 + $200 each additional scene	General Public
Level 1R Single Scene	$600.00	Approved USGS researchers only*
Level 1G Single Scene	$600.00	General Public
Level 1G Single Scene (3 scene maximum)	$600 first scene + $250 each additional scene	General Public
Precision Correction (Level 1P) (single scene)	$725 per scene	Approved USGS researchers only*
Precision Correction (Level 1P) (multi-scene; 3 scene maximum)	$725 per scene + $400 each additional scene	Approved USGS researchers only*
Terrain correction (Level 1T) (single scene)	$800 per scene	Approved USGS researchers only*
Terrain correction (Level T) (multi-scene; 3 scene maximum)	$800 per scene + $425 each additional scene	Approved USGS researchers only*

(Chart 5: Showing the cost of Landsat 7 images and the corrections. * Under current USGS policy, precision and terrain corrected Landsat 7 products can only be distributed to USGS researchers. <http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter12/chapter12.html>)

ASTER: Bands and Resolution

Characteristic	VNIR	SWIR	TIR
Spectral Range	Band 1: 0.52 - 0.60 µm Nadir looking	Band 4: 1.600 - 1.700 µm	Band 10: 8.125 - 8.475 µm
	Band 2: 0.63 - 0.69 µm Nadir looking	Band 5: 2.145 - 2.185 µm	Band 11: 8.475 - 8.825 µm
	Band 3: 0.76 - 0.86 µm Nadir looking	Band 6: 2.185 - 2.225 µm	Band 12: 8.925 - 9.275 µm
	Band 3: 0.76 - 0.86 µm Backward looking	Band 7: 2.235 - 2.285 µm	Band 13: 10.25 - 10.95 µm
		Band 8: 2.295 - 2.365 µm	Band 14: 10.95 - 11.65 µm
		Band 9: 2.360 - 2.430 µm	
Ground Resolution	15 m	30m	90m
Swath Width (km)	60	60	60

(Chart 6: ASTER Systems: Resolution and Bands.)

QuickBird: Bands and Resolution

Panchromatic	Multispectral
6060-centimeter GSD* at nadir	2.4-meter GSD* at nadir
Black & White: 445 to 900 nanometers	Blue: 450 to 520 nanometers
	Green: 520 to 600 nanometers
	Red: 630 to 690 nanometers
	Near-IR: 760 to 900 nanometers

(Chart 7: Quickbird, sensors and bands. *Ground Sample Distance)

SRTM Pricing

Product	Media	Price	Base Charge
Seamless “Finished” United States 1 Arc-Second (30 meter)	Instantaneous download	No Charge	N/A
Seamless “Finished” Global 3 Arc-Second (90 meter)	Instantaneous download	No Charge	N/A
SRTM Format “Finished” United States 1 Arc-Second (30 meter)	DVD	$60 per DVD	N/A
SRTM Format “Finished” Global 3 Arc-Second (90 meter)	DVD	$60 per DVD	N/A
SRTM DTED® Level 1 (3 arc second) (Global Coverage)	DVD	$60.00 per DVD	

SRTM DTED® Level 2 (1 arc second) (United States and territorial islands)	DVD	$60.00 per DVD

(Chart 8: SRTM Prices.)

SPOT: Bands and Resolution

Black and White	Colour
2.5m	2.5m
5m	5m
10m	10m
	20m

(Chart 9:SPOT Resolution and Spectral range.)

SPOT Scene Size

½ scene	42km x 42km
¼ scene	30km x 30km
1/8 scene	21km x 21km

(Chart 10: SPOT image extraction sizes.)

Satellite References

Satellite	**Website**
SPOT	http://www.spot.com/html/SICORP/_401_.php
ASTER	http://asterweb.jpl.nasa.gov/
Landsat	http://landsat.gsfc.nasa.gov/
SRTM	http://www2.jpl.nasa.gov/srtm/index.html
QuickBird	http://www.digitalglobe.com/about/quickbird.html

(Chart 11: Satellite and website)

Satellite Price Comparison

Sensor	**Spatial Resolution (m)**	**Radiometric Resolution (nm)**	**Cost (US$) per scene**	**Scene Size (km)**
AVHRR	1100	5 bands, 0.58-12.5	100	3000 x 1500
Landsat MSS	80	4 bands, 0.5-1.1	425	170 x 185
Landsat TM	30 (120 m band 6)	7 bands, 0.45-2.35	1500	70 x 185
Landsat ETM+	15	Pan (band 8), 0.52-0.90	1500	170 x 185
SPOT XS	20	3 bands, 0.5-0.89	1250	60 x 60
SPOT PAN	10	1 bands, 0.51-0.73	1250	60 x 60
IKONONS	1	4 band, 0.45-0.88	6050	11 x 11
QuickBird Pan	0.61-0.72	1 band, 0.45-0.90	6120	16.5 x 16.5
QuickBird	2.44-2.88	4 bands 0.45-0.90	6800	16.5 x 16.5
CORONA	2+	Single Photographic image	18	17 x 232

(Chart 12: Price Comparison)

Regression Analysis: Visibility

Regression Statistics					
Multiple R	0.569022982				
R Square	0.323787155				
Adjusted R Square	0.318851294				
Standard Error	0.017565018				
Observations	139				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.020239228	0.020239	65.59893	2.7E-13
Residual	137	0.042268589	0.000309		
Total	138	0.062507817			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	

Intercept	0.039056344	0.002904	13.44916	8.19E-27
X Variable 1	-0.000436438	5.38858E-05	-8.09932	2.7E-13

(Chart 13: Regression Analysis, Visibility vs. Vegetation Density)

Regression Analysis: NDVI

Regression Statistics					
Multiple R	0.63106669				
R Square	0.39824517				
Adjusted R Square	0.3938528				
Standard Error	0.22818234				
Observations	139				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.720799401	4.720799	90.66747	8.28614E-17
Residual	137	7.133203423	0.052067		
Total	138	11.85400282			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	0.73505294	0.037725063	19.48447	2.57E-41	
X Variable 1	-0.0066655	0.000700016	-9.52195	8.29E-17	

(Chart 14: Regression Analysis, Visibility vs. NDVI)

Size examination

Tract #	Visibility	Sherds	Distance	Density	NDVI Mean	Vegetation Density
6165	0	0	115	0.00	0.026116	0.4792
8188	0	216	275	78.55	0.010419	0.2406
8059	70	5	35	14.29	0.060025	0.872300
8183	0	83	299	27.76	0.006861	0.1753
12032	0	0	225	0.00	0.007503	0.3611

(Chart 15: Tract Data, 6165, 8188, 8059, 8183, 12032)

Data Analysis: NDVI vs. Vegetation

Tract #	Visibility	NDVI Mean	Vegetation Density
8023	80	1218	0.78817734
8022	80	1159	0.578947368
8021	80	1271	0.72147915

(Chart 16: Tract Data, 8119, 8187, 8192)

Regression Analysis Revised: NDVI

Regression Statistics					
Multiple R	0.66898476				
R Square	0.44754061				
Adjusted R Square	0.44325798				
Standard Error	0.0160649				
Observations	131				
ANOVA					
	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.026969807	0.02697	104.5013	2.48175E-18

Residual	129	0.03329245	0.000258	
Total	130	0.060262257		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.04544345	0.002954199	15.38266	5.7E-31
X Variable 1	-0.0005473	5.35424E-05	-10.2226	2.48E-18

(Chart 17:Regression Analysis, revised NDVI vs. Artifact Density)

Regression Analysis Revised: Vegetation

Regression Statistics					
Multiple R	0.777796				
R Square	0.604967				
Adjusted R Square	0.601807				
Standard Error	0.188416				
Observations	127				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.795828	6.795828	191.4291	5.61231E-27
Residual	125	4.437561	0.0355		
Total	126	11.23339			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	0.84354	0.034913	24.16098	6.24E-49	
X Variable 1	-0.00893	0.000646	-13.8358	5.61E-27	

(Chart 18:Regression Analysis, revised Vegetation vs. Artifact Density)

Regression Analysis: Visibility

Regression Statistics					
Multiple R	0.473602308				
R Square	0.224299147				
Adjusted R Square	0.218637097				
Standard Error	24.52792882				
Observations	139				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	23832.83321	23832.83	39.61448	3.90138E-09
Residual	137	82421.84305	601.6193		
Total	138	106254.6763			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	37.76696552	2.479638038	15.23084	2.87E-31	
X Variable 1	0.433865239	0.068933114	6.294003	3.9E-09	

(Chart 19: Regression Analysis Visibility vs. Artifact Density)

NDVI vs. Artifact Density

Regression Statistics	
Multiple R	0.349952348
R Square	0.122466646
Adjusted R Square	0.116061293
Standard Error	0.020009613
Observations	139
ANOVA	

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.007655123	0.007655	19.11942	2.41135E-05
Residual	137	0.054852695	0.0004		
Total	138	0.062507817			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	0.023679964	0.002022861	11.70617	2.27E-22	
X Variable 1	-0.000245891	5.62349E-05	-4.37258	2.41E-05	

(Chart 20: Regression Analysis: NDVI vs. Artifact Density)

Vegetation vs. Artifact Density

Regression Statistics					
Multiple R	0.470069292				
R Square	0.22096514				
Adjusted R Square	0.215278754				
Standard Error	0.259627491				
Observations	139				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.619321389	2.619321	38.85863	5.27075E-09
Residual	137	9.234681435	0.067406		
Total	138	11.85400282			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	0.51573912	0.026246904	19.64952	1.1E-41	
X Variable 1	-0.004548429	0.000729655	-6.23367	5.27E-09	

(Chart 21: Regression Analysis, Vegetaton vs. Artifact Density)

Data Analysis: NDVI vs. Vegetation

Tract #	**Visibility**	**Density**	**NDVI Mean**	**Vegetation Density**
8119	90	140.000000	0.004313	0.110070258
8187	70	144.881890	0.008911	0.209090909
8192	95	136.363636	0.002504	0.212543554

(Chart 22: Tract Data, 8023, 8022, 8021)

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