An Evaluation of Google Earth for Archaeological Exploration and Survey

Scott Madry

Department of Anthropology
The University of North Carolina at Chapel Hill
Chapel Hill, NC USA
madrys@email.unc.edu

Abstract

An analysis of the utility and limitations of the new Google Earth software and online data environment was conducted to determine the capability of the system for the survey and discovery of archaeological features in France. The author has conducted such regional analysis, including aerial archaeological survey, for over 25 years. This paper describes the capabilities and limitations of Google Earth for regional archaeological survey and site location. An area of the Burgundy region of France was surveyed and a surprisingly large number of previously recorded and new archaeological sites were located. The system has significant benefits for this work, but also has limitations that could be addressed to make the tool even more useful.

1 Introduction

As reported by nature.com and the BBC on November 5, 2005, an Italian computer programmer, Luca Mori, used Google Earth to search satellite imagery of his home town of Sorbolo, Italy and found signs of a Roman villa beneath a river bed. According the story, archaeologists from the National Archaeological Museum in Parma were contacted and confirmed the site, and now plan to excavate the villa (Daily Telegraph 2005). I decided to conduct an analysis of Google Earth to determine its utility for professional archaeological site prospecting and survey. I have conducted this work for over 25 years in France using a variety of techniques, including aerial survey from low flying aircraft, stereo air photo analysis, field survey, digital image processing and remote sensing, and the development of regional archaeological predictive models using GIS (Madry and Crumley 1990; Madry and Rakos 1995; Madry 1987, 2005).

2 Aerial Archaeology and Survey

Aerial archaeology and survey is an old and established technique that has been used in Europe for many decades (Crawford 1923; Madry 2005). Buried archaeological features, including roads, buildings, walls, enclosures, and other evidence of past human occupation, can be seen from the air or in aerial photos. This is because these features can impact the growth of crops or grass, or show up as different colors of soils, or as shadows. Any feature on the landscape that has a regular geometric shape such as straight lines, circles, or rectangles may be an expression of buried archaeological features. There are also a surprisingly large number of "false positive" features as well—buried water lines, modern earth moving, karst topography, old stream channels, etc.—that can mimic archaeological features. It is through many hours of observation and analysis that a trained interpreter learns the difference, and field investigation is required for a positive identification. Once a potential site is located, it can be further investigated using non-destructive geophysical testing, including ground penetrating radar, resistivity, and magnetometry. These can provide important confirmation about the nature of the buried features. Ultimately, sites can be tested archaeologically and excavated, although permits are required for any excavation work in France, and can be difficult to acquire.

Aerial prospecting, while very useful, does have significant drawbacks. Flying in Western Europe is expensive (compared to the U.S.), and the logistical issues are significant. For American researchers, the opportunities to fly are usually limited to short summer field seasons, and access to aircraft, scheduling, and weather all make a short flight over a small study area a complicated and expensive, all-day affair. The weather must be clear and winds calm, and I have often waited weeks for good conditions, as my field time evaporates. Once in the air, the plane is always moving so it is very difficult to remain oriented, and air sickness can be a problem for those unfamiliar with low-level flying. Once an interesting feature is located, the position of the aircraft is saved using GPS and various photographs are taken of the area. GPS has proved to be very useful, as before the general availability of GPS receivers we struggled to locate individual fields on our folded maps in the cockpit. On more than one occasion, before the availability of low-cost GPS, I was unable to locate sites on the ground due to incorrect map coordinates recorded in haste in the air. Flight safety is paramount, and there is a small but very real danger in low-level flying. The aerial photos and GPS data are then analyzed later, on the ground, and interesting features are located on maps and surveyed on foot. There are also certain areas where flying is not permitted, such as various restricted areas in Western Europe including military operations areas. Most of the Middle East, Turkey, and Greece do not allow any aerial prospecting and limit access to all vertical aerial photography for national security reasons.

Analysis of vertical mapping aerial photography is also a very useful tool for site survey and analysis. Mapping photos can be purchased in France from the Institut Géographique National in Paris. Various dates back to the 1950s are available in black and white or color. A trained photo interpreter can use stereoscopes to magnify a small area and, when viewing two overlapping photos, see the topography in three dimensions. A very large number of photographs are required to cover a large area, which can be a significant cost. There is also the logistical problem of handling many different overlapping photo pairs, lining up the stereo pairs, and recording any site information accurately on an adjacent map. This is a very useful but complex process that can be very time consuming and is quite difficult on the eyes. Alas, in many areas of the world, aerial mapping photos are considered to be military secrets and are not available to the public or academic researchers.

Digital image analysis of aerial photographs can also be conducted. Aerial photos can be scanned and the digital data entered into an image processing system. This can include enhancements such as density slicing, contrast stretching, spatial filters, searching for certain linear orientations, and classification of data into various land use or land cover categories. Until recently, space remote sensing imagery has not been of sufficient spatial resolution for the location of archaeological sites, but new ultra-high resolution space imagery on the order of one meter pixels and less have recently come onto the commercial market. These have finally made space imagery useful for archaeological surveying, but the cost of the imagery is very high and is usually out of reach for archaeologists, especially since one must also include the cost of image processing software, hardware, and training. This combination of cost and complexity has largely kept these powerful new tools out of the hands of most archaeologists.

3 Google Earth

Google Earth was introduced in October of 2005. It is based on proprietary technology developed by Keyhole, a commercial mapping firm that was purchased by Google in October, 2004. Google Earth is a computer system that interactively streams more than ten terabytes of Earth information (satellite images, elevation, vector and point data) to personal computers over the Internet. The user loads only the Google Earth software on their computer and the data is served remotely. Google closely guards its underlying server technology, internally referred to as the "Googleplex." It is believed to consist of some 100,000-150,000 inexpensive linked PC servers in 24 data centers, all running as a single entity using a highly customized version of Linux. The image data reside on these Google servers and is provided in real time over a high speed internet connection to the user. Google Earth contains space remote sensing data at various levels of detail, and also vector data representing roads, political boundaries, hydrology, etc. Global imagery coverage is available using orthrectified Landsat7 ETM true color data of 15 m spatial resolution. But for significant areas of the world, color Digital Globe ™ color imagery of 0.7 m

resolution is available. The stated mission is to "provide the visual context for understanding the world's information."

Michael Jones, CTO of the Google Earth team, gave a presentation at the second Map Middle East Conference in 2006 in which he described Google Earth as "the GIS for the 5.999999 billion people of the world's 6 billion population who don't know or care what GIS is." He also stated that Google Earth was inspired by an idea of "the father of GIS," Roger Tomlinson, who in the late 1960s wrote that the ultimate GIS would be a computer globe of interactive data. The third inspiration is Mr. Spock's Tricorder from the Star Trek series, which provides needed information automatically.

There are currently three levels of Google Earth software.

- *Google Earth* is free and provides the basic capabilities of viewing the Earth from your own computer.
- *Google Earth Plus* costs $US20 per year and is an optional upgrade that provides GPS device support (verified for Magellan and Garmin devices only), the ability to import small spreadsheets, drawing tools, and higher resolution printing.
- *Google Earth Pro* costs $US400 per year and is for professional and commercial users such as real estate firms. It includes the capabilities of Google Earth Plus and still better printing, larger spreadsheets (importing 2,500 compared with 100 records), area measurements, and improved product support. You can also purchase a movie making module, premium printing module, and GIS data importing module for an additional $200 per year each.

This analysis was conducted using the free Google Earth and Google Earth Plus version 3.0.0764, build date November 15, 2005. Two computers were used, an IBM desktop computer (running Microsoft Windows XP Professional, with a Pentium 4, 3 GHz CPU, and with 1 GB of RAM), and a Sony VAIO laptop (running Microsoft Windows XP Home Edition, with a Pentium 4, 2.4GHz CPU, and with 512 Mb of RAM). Internet access was provided using a wireless cable modem.

The Google Earth software can be downloaded from http://earth.google.com/download-earth.html. There were over 100 million downloads of the software in the first year. A beta version for Macintosh computers was released in 2006, and a Linux version is also now available. The system does require a fairly recent computer and high speed internet connection. The software is very intuitive and easy to use, especially when compared with much less intuitive commercial GIS and remote sensing software. When you start the software you are presented with an Earth globe in the screen. At the top are a few pull-down windows and at the left are the various different places and data layers that can be turned off an on. At the bottom center are the various controls that allow you to zoom, roam, rotate the image, and control the vertical or perspective view. The mouse can also be used to pan the image, and the mouse wheel controls the zoom in and out. A north arrow appears at the bottom left of the image, along with the Lat/Long coordinates and elevation of the center point of the screen. At bottom right is the eye altitude of the viewer. The initial default view is

of North America. The user can turn on or off various point, vector, and raster GIS data layers, including roads, hydrology, international borders, the Digital Elevation Model (DEM) terrain, and three-dimensional (3D) building footprints (available for certain major U.S. urban areas only) at bottom left.

As the user zooms in to a particular area, the spatial resolution of the image automatically changes and various levels of detailed features will appear. The entire planet is covered by 15 m satellite color imagery (with a few exceptions in Oceana), but a significant percentage has 1 m or 0.7 meter color images available. These areas are clearly visible. Imagery is available for the entire world, with spatial resolution varying from global 15 m satellite coverage to city centers displayed at 30 cm and 15 cm. The Google Earth campus in California has 15 cm, or 1 in pixels. Global 90 m DEM terrain data for the entire world is derived from the NASA Shuttle Radar Topography Mission and provides an accurate portrayal of mountains and valleys everywhere. Enhanced transportation network data for countries in western Europe shows highways, city streets, and even small alleys and dirt roads.

3.1 Placemarks

Placemarks are the tool in Google Earth that allows you to digitally "put a push pin in the wall map and mark it with a sticky note." You can click on the "push pin" icon at the lower right of the screen and choose to place a new placemark on the image. You can manually adjust the location by simply moving the icon, and then you can add comments and text for that feature.

When you add a new placemark, the software opens a new window that allows you to create a name and longer description to the feature being marked. You can create a new folder or put the icon in an existing folder. More advanced features available include the style of the icon (color, size, etc.), location of the placemark, and height of the placemark (they can float in the air above the feature if you wish). You can create your own icons, as well. It automatically saves the elevation and coordinates of the placemark as Lat/Long in degrees, minutes, and seconds. Google Earth uses WGS84, not the system that French files use (Lambert Conic Conformal), so the user must be careful in transferring data between the systems (as with all GIS environments).

The elevation of the placemark is presented at the bottom of the screen, and is automatically saved in the placemark description, along with the geographic coordinates. Elevation values are derived from 90 m SRTM data, and therefore are approximate, but I found them to be consistent with 1:25,000 maps of the region. Once the placemark is saved it can be turned on and off in the "places" folder at the left of the screen to see a group of sites displayed on the screen or not. Whenever you left click on the placemark it will show you all of the description information, using a scroll bar if the text is long. The user can right click on the placemark and edit the contents, rename, cut, copy, paste, or delete it. When you create or edit a placemark or folder, you can change the icon for that item by clicking on the icon button to the right of the *Name* field and choosing a new icon from the palette. This is useful for marking road segments with one icon and possible sites with another, for example.

Later, when you click on the placemark, you will see all the information, as well as how to navigate to that location (a map and driving directions). These driving directions are extremely useful for the aerial archaeology application, as it provides specific driving directions from a given location to the feature on the ground, but this feature currently does not work in France. This will be very useful in navigating to specific locations in the field, but I found that this could be done with hard copy printouts and GPS coordinates, as well. Simply clicking on the printer icon at lower right will print out a copy of the screen, which can be saved for future field visits, publications, etc. If you double-click on a placemark icon on the list at left, the software will fly you to that location.

The ability to immediately annotate your discoveries with the elevation and coordinates, make measurements, and print a color image is extremely useful. One limitation is that, at present, you can download GPS data, but only in the Google Earth Plus version, costing US$20 per year, not the free version. At present, you cannot upload the coordinates of a set of placemarks to a GPS receiver. This currently has to be done manually. But once this has been done, the researcher can then take the screen images and GPS coordinates, and accurately locate each individual feature on the ground for further analysis.

One warning is that the system will automatically put new placemarks in your "temporary" folder. Unless these are put into a permanent folder, these will be automatically deleted at the end of your session. It will prompt you to move them when you close a session.

You can email any placemark, shape, or folder to another Google Earth user from within the Google Earth application, or you can also email any KMZ file (the Google Earth file format) located on your computer to a Google Earth user. In addition, you can post a .kmz file (the Google Earth file format) to the Keyhole BBS where other Google Earth users can view the information, or you can serve the file on your own Web server or from any network location. When you click on the "email" icon, the system will email the placemark using your existing mail browser. The recipient will receive an email stating: "You have been sent a Google Earth Placemark(tm)." If the recipient has Google Earth installed, they can simply double-click on the attached Placemark file and it will fly them to that location. People can also share entire placemark folders or serve their own data. This can be a very useful tool in scientific collaboration. An archaeologist at one location can share their placemarks with others on a different continent. They can open it and immediately be taken to that location to see the feature and verify the site or give their opinion regarding the nature of the feature.

3.2 Google Earth Tour

Another interesting feature is the Google Earth Tour. You can set up a tour of a set of placemarks and the software will start a fly-through visit to each site in turn. This is a very useful capability for sharing multiple sites of interest between collaborators. It also has potential for education at a variety of levels.

3.3 The Google Earth Community

You can also share your placemarks with the entire Google Earth community, but clearly this should not be done with unprotected archaeological sites or other sensitive information. If you right click the placemark icon and choose to "share with Google Earth Community." The placemark will be sent to the Google server and be made freely available to all users. These placemarks can be displayed by clicking on the "Google Earth Community" folder under the green "Layers" list on the left portion of the screen. This is a fascinating aspect of this technology. Any user can post lists of sites, and there are thousands already posted that are immediately accessible. I was able to download a placemark file of all 36,585 towns and villages in France containing altitude, postal codes, and other data. This proved to be very useful in determining the specific location of individual features in relationship to local towns.

The Google Earth Community is a very large and useful resource. You can access the community via the very large bbs at http://bbs.keyhole.com. Thousands of topics are including, specific discussion groups, including topics such as history and archaeology. There are a wide variety of such collections of placemarks that can be downloaded. For my French research, there are collections of placemarks, for French chateaux, formal gardens, and even an 18th century color Cassini map of the Paris region (maps can be served as well as points or vector linear features). Over 800 British stone circles and a collection of Roman era amphitheaters are posted on the Google Earth Community website.

4 Method

A Digital Globe 0.7 m true-color image was analyzed for this project. The image is cloud-free and was acquired on June 30, 2004. It covers and area of 18 km wide by 80 km along the north-south axis. The DEM of the region is from the NASA STRM radar interferrometry dataset (http://srtm.usgs.gov) and has a spatial resolution of 90 m. The area covered is immediately to the east and south of the city of Dijon, France in the Burgundy region. This area is very rich in human occupation and archaeological resources ranging from the Paleolithic right up to the modern era. There was extensive Iron Age, Gallo Roman, and Medieval occupation. The area has been well surveyed by archaeologists, including extensive low-level aerial surveys by Renée Goguey (Goguey 1995, 1996, 1999).

I visually reviewed the entire 0.7 m image in multiple viewing sessions at a display resolution of some 1,200 m across. This is the equivalent of flying over the area at 400 m (1,200 ft) above the ground. Viewing even smaller areas works very well, but you can quickly loose context. I visually reviewed a very small area of a few fields at a time, looking for various indications of buried archaeological features in the same way that I would if conducting low level aerial survey from an aircraft or conducting manual stereo photo interpretation. It was very simple to zoom in on a potential site and do a perspective view at low level and then rotate 360 degrees to look at the surrounding area.

Four complete visual reviews of the entire study area were conducted at a very large scale (meaning that features in the viewing image are large). A first review was done from left to right and right to left, from top to bottom, throughout the entire image. The actual viewing area differed, but, at most, five or six individual farm fields were visible at one time, an area measuring perhaps 1-1.5 km on a side. At viewing elevations below 300 m the image looses clarity due to the 0.7 m pixels. This initial view took some six hours spaced over a single weekend, and was conducted by manually grabbing the image and pulling it to the side to view the next area. A second process of viewing was conducted along the major waterways, and a third was conducted in the immediate vicinity of the major concentrations of sites that were located. Each individual agricultural field was inspected visually for evidence of vegetation marks or soil changes. When an interesting feature was located, I would often rotate the image around its axis to view the area around a 360 degree turn. The ability to view the image in a 3D perspective view was also very useful when using the elevation data to provide relief, especially for linear features such as possible old roadways and features that occupied hilltops. A final, fourth survey was conducted randomly over the entire image.

As Google Earth serves spatial data from a remote server located in California, the data are sent in small areas which are referred to as tiles. These tiles are refreshed as you move or change scale, and at the maximum resolution only the center half of the image is at the maximum resolution, so you must focus your visual analysis there. The refresh rate was surprisingly fast and I never had the feeling that I was waiting for the data. I would move the viewing area and the image was redisplayed in real-time.

One very interesting feature is that you can set the image to pan across the screen automatically at different speeds. This can be done in either the vertical setting or as an oblique view. At slow speeds and altitudes in a high oblique perspective (with the horizon visible), the feeling is very much like flying over the landscape in a small aircraft, but without the noise, turbulence, and distractions. Unlike real flying, when you locate an interesting feature in a field, you can stop the motion, zoom in or out, rotate to vertical, and view the feature in any number of perspectives. Two buttons at the bottom of the screen automatically return the image to a "North at top" and vertical view to continue the systematic review of the image. The screen image can be saved at any time in a variety of formats, including .jpg. The coordinates and viewing altitude are constantly displayed on the screen as well.

I conducted visual analysis at a variety of scales,

including 270, 550, 1,200, 2,250, and 5,600 m across, representing an area of a few fields to portions of a single field. A visual view of 270 m across is the maximum possible without blurring the Digital Globe 0.7 m resolution. A viewing altitude of 1,200 m was used to conduct initial analysis over the entire area, 400-500 worked well for looking at an individual field, and 300 m worked well for looking at an individual potential feature. The visual analysis and review of the image was very simple to do and not nearly as tiring as traditional air photo interpretation using a stereoscope. The instant ability to zoom in and out, rotate, and see the area in a 3D perspective view over the elevation file was extremely useful and simple to do.

The use of vertical exaggeration for micro relief was also very useful. I found 3X or 4X exaggeration to work well in this area of gentle rolling hills. This is the same vertical exaggeration that is provided when doing manual stereo photo interpretation. The vertical exaggeration can be altered by going into the "Tools" pull-down menu at top and clicking on "Options." You can choose a variety of viewing options, including elevation exaggeration and recording your elevation in English or metric units. When I located an interesting field, I found it useful to go to a high oblique view that just shows the horizon, and then rotate around it 360 degrees to see the feature from all angles. In aviation and aerial archaeology, this is referred to as a pylon turn. This places the site in context and also helps in orienting and seeing spatial patterns, especially if you are looking at linear features such as road networks. You can then rotate the image back to vertical and, if you want to mark the site, you can add a new placemark (discussed later) at that location.

5 Results

In the course of this analysis, I was able to locate a surprising number of definite archaeological sites. This area of Burgundy is not my regular research area, which, alas, does not have Google Earth 0.7 m coverage available at the present time. Therefore, I did not know at the time if these sites are newly recorded or were already known, but I was certain that they are the type of archaeological sites that are frequently located by low-level aerial survey and stereo vertical photo analysis in France.

One new site (Figure 1) consists of two square, positive crop marks that are also in association with an intersection of an old roadway and other linear features, one of which bisects one of the structures. The two structures are located in a field with a mature, green, winter wheat crop. These mature crop fields are often very good for locating buried cultural resources. The size of these features measured some 20 m and 15 m on a side. This was easily determined by using the "Measure" tool in the "Tools" pull down menu. This tool is very useful for determining both the size of individual features and the distance to the edge of a field, streams, or other features on the landscape—useful information for locating the site later on foot.

A second site is located not far away from the first. It is a circular soil mark measuring some 30 m across (Figure 2). This feature is in association with a long, linear feature that clearly represents an ancient roadway. The path is extremely straight and runs for over 5 km across different fields, and was similar to other Gallo-Roman era roads that I have located in the past in the region. There appeared to be two branches or intersections with another road sections, as well.

An example of the potential use of the integrated Google Earth data was that a small village lies a few kilometers to the south of this roadway. When the "Roads" icon at the bottom of the Google Earth screen was turned on, it showed a vector GIS roads overlay, which includes the names of each road. A modern road section connected up on a straight line with the linear feature I identified. This road was labeled "Impasse de la Voie Romaine" or "dead end of the Roman Road," a clear indication that the section of this road was indeed an old Roman roadway (Figure 3). This example clearly shows the utility of the Google Earth environment for this type of analysis. It was very useful to mark the road location with several placemarks to give the orientation of

Figure 1. Two square positive crop marks that are also in association with an intersection of an old roadway and other linear features.

Figure 2. A circular soil mark measuring some 30 m across in association with a Roman road (at left). The black features are electrical power lines.

333

Figure 3. A perspective view of the Roman Road. The circular feature is at bottom, just above the push pin. The modern "Impasse de la Voie Romaine" is shown at top center, in line with the ancient road below.

Figure 5. A group of three, large, circular features. Each appears to be a raised feature surrounded by a lower area. The largest feature is at the top.

Figure 4. A ground view of the Roman roadway, running diagonally across the picture from bottom left to top right. The road was clearly visible as a raised, straight roadway.

Figure 6. The largest of the round features in Figure 5, shown from the ground. The raised area is clearly visible at top, as is the darkened lower area surrounding it. This area has enhanced vegetation due to water retention. A significant amount of medieval ceramics were scattered throughout the feature.

the road. I then used the 3D perspective view to look along the known road segment and to move forward along that line to see if I could see any additional vestiges (Figure 3). In several cases, this technique worked, and I was able to locate additional road segments and to "connect the dots" of multiple road segments in the image. This area is also shown in a ground image (Figure 4). The road was clearly visible on the ground as a raised, straight roadway.

A third area located nearby contained a large circular feature, which appeared to be a raised central area surrounded by a depression or moat. Two similar but smaller features were located in adjacent fields (Figures 5 and 6).

A fourth area of interest was located that exhibited evidence of early field divisions, often referred to as a "Celtic fields" (Figure 7). The regular field divisions measured between 60 and 80 m on a side, were all oriented along a NE-SW axis, and were widely distributed across an area measuring over 5 km across. Celtic fields are remnants of

Iron Age (or even earlier) land divisions that created small fields bounded by ditches (Klamm 1993).

A fifth site is a group of at least nine round features in two adjacent fields that closely resemble Iron Age tumuli (Figure 8). This field also includes a large, rectangular feature. Many other positive and negative crop marks and soil marks were located throughout the study area.

A large Gallo-Roman villa complex was located. The visible structure (Figure 9) measures some 80 by 180 m and is oriented along a north-south axis. Individual rooms are clearly visible, and additional features are located in the adjacent fields.

Detailed images of interesting features were saved as .jpg files and limited digital image processing was conducted using commercial image processing software. Analysis included density slicing and contrast stretching

Figure 7. An area of "Celtic Field" divisions. A very large area of these, covering several square kilometers, was located. The field divisions show as a series of regularly spaced dark lines that cross modern field boundaries.

Figure 8. A group of nine round features that closely resemble Iron Age tumuli. There is also a large rectangular feature associated.

that visually enhanced the images for interpretation. In all, a surprisingly large number of definite archaeological features or groups of features were identified in this quick, visual analysis of the image: five major road segments and several smaller ones, eight possible quarry sites, and other possible features. Each of these features was marked with a placemark, and relevant information such as size, orientation, and distance from nearby landmarks was recorded using the Google Earth tools.

Field verification was conducted in March, 2006. A visit was made to the Ministry of Culture, Service Archeologique du Bourgogne in Dijon to determine if these sites were already recorded in the national French archaeological database. The area is well known archaeologically, and had been previously flown extensively by aerial archaeologist Renée Goguey. The Gallo-Roman era road was known, as was the circular feature in association with it. Portions of the positive crop marks (Figure 1) and some of the nine round tumuli

Figure 9. A large Gallo-Roman villa complex, measuring some 80 by 180 m.

structures (Figure 8) had also been previously discovered in an aerial survey by Goguey in 1999, but additional, new features in association with these were discovered by this project. Goguey had also located the larger of the three ringed structures (Figure 5), but not the two smaller ones. The Celtic field patterns were new, as were the majority of the other less obvious sites that were located farther from the immediate area of the airfield near Dijon.

As many sites as possible were visited on the ground using a combination of printed maps of the Google Earth images and GPS. Locating the individual fields was aided by the fact that over 36,000 place names in France are available through Google Earth community, and that all roads, including small dirt tracks in the area, are automatically labeled. Color hardcopy images were used to locate the fields, and the GPS was used to locate individual features. A digital camera was used to take ground images. Unfortunately, the winter wheat had already been planted in most of the fields, so ground cover was extensive and this limited surface visibility.

Placemarks of all features have been sent to the Ministry of Culture staff in Dijon for review. Additional field work will be conducted in September of 2006, after the wheat crop is harvested and surface visibility will be improved.

6 Discussion

An area of 1,440 sq. km of eastern-central France was systematically analyzed from my office in the U.S.A. using Google Earth and 0.7 m color satellite imagery. A surprising number of previously recorded and new archaeological sites were located using this method. A total of 101 features, including roads, positive, negative, and soil marks representing probable Iron Age, Gallo-Roman, and Medieval sites were located in a surprisingly small number of hours of visual inspection (Figure 10).

I found this method of site survey to be a very useful addition to existing archaeological prospection techniques. It was not as hard on the eyes as manual stereo photo interpretation, and I was able to do it for longer sessions and with
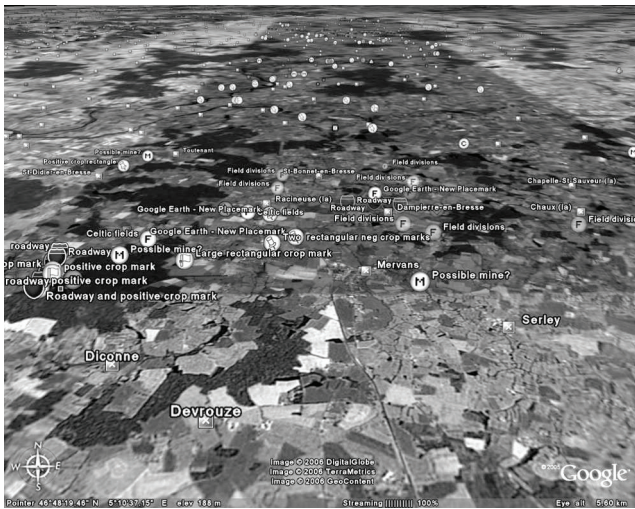
Figure 10. A perspective view of the entire study area looking north. Dijon is in the upper left of the image. This shows the total of 101 recorded archaeological features that were discovered. They are marked with different icons for roads, positive, negative, and soil marks representing probable Iron Age, Gallo-Roman, and Medieval sites. These sites were located in a surprisingly small number of hours of visual inspection.

more concentration and less eye strain. I found the ability to rotate the image at will and to easily view small areas in oblique perspective to be very useful. The system's ability to "fly" across an image at a given speed was also an interesting feature that made visual analysis easier. The ability to create new placemarks at the location of identified features, and to automatically store Lat/Long and elevation for that place, along with additional data was very valuable. The measuring tool allowed me to quickly measure features, and to record the location of the feature in relationship to nearest water source, field edges, or the nearest villages.

I found it extremely useful to use the perspective view with a 3X vertical enhancement of the DEM for analysis of road systems. Once a section of a roadway was located and marked with placemarks, a low oblique view along the path gave an excellent perspective of the local context out to the horizon.

The ability to rotate a perspective view around an individual field is helpful in determining parallel lines. Lowering the perspective view with the elevation data provides a good, long view of the area and other features that may line up.

The ability to share placemarks with colleagues around the world, and for them to be able to instantly view that location on their Google Earth system, may be one of the most unique and useful capabilities. The ability to share interesting site locations, prompt discussion, report sites to local authorities, etc. all can enable a new level of collaborative research and interdisciplinary interaction among international research projects. The fact that the basic Google Earth software is fee is certainly a benefit to archaeologists, but the system does require high-speed Internet, which is much less common outside of North America.

There are now several add-ons that are available, including tools to convert ArcGIS point, polygon, and raster data

into Google Earth data format. Users can also serve their own data, including raster, vector, and point data.

7 Conclusions

Google Earth and high resolution satellite imagery have significant potential for systematic professional regional archaeological analysis and survey. The ability to quickly and easily survey large areas for archaeological sites from any computer with a high speed internet connection is very valuable. The ability to share placemarks via the internet, allowing collaborators to share data and view sites within the Google Earth environment, is an important improvement in our ability to collaborate around the world, and to protect and study our endangered cultural resources around the world.

Google Earth has significant potential for use in regional archaeological prospecting and site location where 0.7 m data are available. The basic level software is free, easy to learn and use, and provides some capabilities in real-time that are not available in expensive GIS software that requires a great deal of user knowledge, data acquisition, georegistration, coordinate conversion, etc.

The speed of the system is impressive, with data presented in virtually real-time. Ancillary data such as points, lines, polygons, and raster imagery can be included and served on the users own system.

The incorporation and use of existing GIS data in the Google Earth Pro system makes a very powerful working environment. Tools are available to convert ArcGIS data into Google Earth format.

Google Earth Plus provides additional printing resolution (2,400 pixels, and up to 4,800 pixels in Google Earth Pro), but this did not provide a significant visual improvement on my Lexmark X3350 color printer. The primary improvement is the ability to download GPS locations for viewing in the Google Earth environment. The system only specifically supports Garmin and Magellan receivers at this time. I was able to download and view data from a Garmin eTrex Vista with ease.

Google Earth Pro is the commercial version of the software. It includes the ability to serve your own data, and to import traditional point, line, polygon, and raster imagery in file formats such as .shp and .tab into the Google Earth environment. In Google Earth Pro, you can also measure the radius, perimeter, and area of features, and with the $200 GIS data option, you can include your own point, line, polygon, and raster GIS data in your Google Earth experience.

7.1 Limitations

There are limitations of 0.7 m data for individual field or feature analysis. It gets "fuzzy" just when you want to view an individual feature as you would with higher resolution aerial photography. The development of the next generation of commercial ultra-high resolution satellite imagery will alleviate this problem, with 0.5 m data coming in the next few years.

It would be helpful if you could use the measuring tool while the placemark tool was open.

The inability to upload placemark data and coordinates to a GPS is a limitation that could be easily fixed in future versions. While it is possible to download GPS locations to view on the system, there is no capability at this time to export GPS coordinates out from a placemark file. Once a feature of interest is located and a placemark created, the Lat/Long and elevation are automatically stored, and these are what are needed to conduct field investigations. The user can now copy and paste coordinate data into a spreadsheet for downloading to a GPS, or manually enter the data, but coordinate export to GPS seems to be a logical next step. The ability to create polygons in the software is also very useful, but is only available in the Google Earth Pro version.

The free basic software is not a fully functional GIS, but it does have an impressive set of capabilities for archaeological site prospection when viewing ultra-high resolution satellite imagery. It has some very impressive capabilities, including real-time rotation of an image and real-time 3D perspective views and the ability to fly through a scene, that are not found in even the most complete (and expensive) GIS systems.

7.2 Future Directions

Google Earth Pro has been purchased by the author, and the ability to serve existing ArcGIS data is being evaluated. Additional field work will be conducted in September of 2006 after the winter wheat crop has been harvested. This work will concentrate on new sites that have not already been recorded. The author has begun to enlarge this analysis to other regions in France which have 0.7 m imagery, and additional sites have been located in two additional regions of France, in Alsace and the Auvergne. Initial analysis has located several archaeological sites in both areas, and limited fieldwork will be conducted in Alsace in July of 2006. Google Earth has just (at the time of this writing in June, 2006) come out with a beta version of their next release, Google Earth 4 Beta for Windows, Mac, and Linux, which will also be evaluated. This new version is also available in German, French, Spanish, and Italian, and has improved GPS support. Google has also introduced Google SketchUp, which is an easy-to-learn 3D modeling program that enables users to create 3D models of structures and place them in Google Earth. This will certainly be useful for archaeologists as well. New data are being added constantly, and Google states that 30% of the world's population can now view their homes in high resolution.

The archaeologist's dream of flying over a remote research area at will and viewing the landscape with sufficient detail to actually locate individual archaeological sites is now within our grasp. It is now up to us to integrate this powerful new tool into our research, teaching, and management activities. There is significant potential for fostering collaboration and joint projects across continents.

References Cited

Daily Telegraph UK. 2005. Zooming in. Last Updated: 05/11/2005. http://www.telegraph.co.uk/travel/main. jhtml?xml=/travel/2005/11/05/etgoogle05.xml&sSheet=/travel/2005/11/05/ixtrvhome.html (Accessed 1 December 2005).

Crawford, O. G. S. 1923. Air survey and archaeology. *Geographical Journal* 61:342–366.

Goguey, R. 1995. Archéologie aérienne de la Seine au Danube : quelques aspects des récentes recherches sur la Bourgogne et la Hongrie. In, *Luftbildarchäologie in Mittel- und Osteuropa*. Actes du Colloque de Berlin, 26-30 sept. 1994. Jürgen Kunow, ed., pp. 227-235. Potsdam: Brandenburgisches Landesmuseum für Ur- und Fruumlhgeschichte.

Goguey, R. 1996. Prospection aérienne des sites archéologiques autour du Mont Beuvray. In, *L'environnement du Mont Beuvray,* Olivier Buchsenschutz and Hervé Richard ed., pp. 125-131, fig. 1-20.Glux-en-Glenne, Centre Archéologique Européen du Mont Beuvray,

Goguey, R. 1999. Les éléments du paysage archéologique révélés par la photographie aérienne en Bourgogne : camps, voies, parcellaires. *Mémoires de la Commission des Antiquités de Côte d'Or*, t. XXXVII, 1993-1996, pp. 169-196. Dijon, Académie des Sciences, Arts et Belles - Lettres

Klamm, M. 1993. *Aufbau und Entstehung eisenzeitlichen Ackerfluren ('Celtic Fields')*. Band I Stand der Forschung. Göttingen: Göttinger Bodenkundliche Berichte 102.

Madry, Scott. 2005 Archaeological applications of remote sensing. In, *Remote Sensing for GIS Managers,* Stan Aronoff, ed., pp 376-386. Redlands, California: ESRIPress.

Madry, Scott and Crumley, Carole. 1990. An application of remote sensing and GIS in a regional archaeological survey. In, *Interpreting Space: GIS and Archaeology*, K. Allen, S. Green, and E. Zubrow, eds., pp 364-380. London: Taylor and Francis.

Madry, Scott and Rakos, Lynn. 1996. Line-of-sight and cost surface analysis for regional research in the Arroux River Valley. In, *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*. H.D.G. Maschner, ed., pp. 104-126. Center for Archaeological Investigations, Occasional Paper No. 23. Southern Illinois University, Carbondale, Il.

Madry, Scott. l987. Remote sensing in a temperate regional archaeological survey in France. In, *Regional Dynamics: Southern Burgundy from the Iron Age to the Present*, C. L. Crumley and W. H. Marquardt, eds., pp 173-236. New York: Academic Press.