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GIS Techniques in Archaeology: An Archaeoastronomical Approach

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1. Introduction

Geographic Information Systems (GIS) has proven to be a very useful tool when it comes to represent the elements of an archaeological site. Geographers initially used these systems as resource management tools (Burrough & McDonell, 1988). A geographic information system is a special case of information systems where the database consists of observations on spatially distributed features, activities or events, which are definable in space as points, lines, polylines, or areas. These datasets are composed by a collection of geographic coordinates (latitude, longitude and altitude) or on an UTM projection (X,Y,Z), relative to a reference Datum and alphanumeric information.

Traditionally, this information has been stored on spatial databases as PostGIS or Oracle Spatial, and they have been transformed using geoprocess techniques to get valuable derived information as DEM (Digital Elevation Models), thematic maps, and other relationship between the elements and the environment.

Nowadays this point of view of GIS as a cataloge technique has been improved and we go ahead to Spatial Data Infraestructure (SDI) (IGN, 2011).

While GIS is a data-driven, SDI is a service-oriented. In an SDI the data resides outside of our computer, and they are distributed across the network. Each layer of data is maintained by the team responsible for its data. In Archeology, the layer of interest are related to the archaeological site in study.

An SDI is composed by a set of technologies that includes data and geographic attributes, with services that allow the visualization of this mapping and the integration with other systems. The goal of this technology is effective share of geographic information avoiding duplication and ensuring the use of a set of basic geographic data, enabling the integration of these sources, maintained by different agencies.

Therefore, a SDI is more than geographic information (GI) stored in a traditional GIS. The GI can be accessed via Internet and it can be used with other data sources, this is where the potential of this technology.

GIS have some advantages comparing to other technologies, for example, data is collected just once and kept where it can be managed most effectively. It is possible to combine seamless spatial information from different sources across all over the world, sharing it with a huge amount of users and applications. It allows different levels of detail from the same data source; e.g. detailed for regional research or general for strategic purposes.

In European Union, we can find INSPIRE Dierctive which aims to create a european spatial data infrastructure (EU, 2007). This will develop the sharing of spatial information among public sector organizations activating public access to spatial information across Europe. Globalization and Interoperability are the basis of this technology.

1.1 Services offered by an SDI

There are some services that allow mapping visualization and integration with other systems from data and geographic attributes that shapes SDIs. These services are described as standards by the Open Geospatial Consortium (OGC, 2011a). The OGC is an international industry consortium of 438 companies, government agencies and universities participating in a consensus process to develop publicly available interface standards.

These support interoperable solutions, one of the most important objectives of an SDI. Among its objectives are: Facilitate the adoption of open, spatially enabled reference architectures in enterprise environments worldwide. Advance standards in support of the formation of new and innovative markets and applications for geospatial technologies. Accelerate market assimilation of interoperability research through collaborative consortium processes.

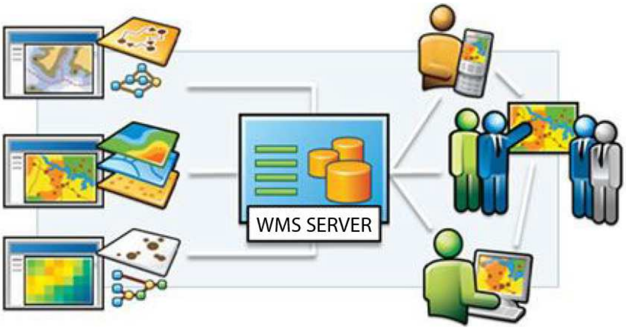


Fig. 1. WMS server structure

The standard services provided are WMS, WFS, WCS and CWS. The layers produced by this method represent a big advantage because they can be mixed with other geographic information get from any source. Users just need a thin client to get these services and geographic data remain in the original service provider.

1.1.1 WMS (Web Map Service)

It is the standard for displaying geographic information over the Internet. It provides a picture of the real world for a requested area. The sources may be GIS data files, spatial databases, digital maps, orthophotographies, satellite images and so on.

WMS is organized into one or more layers, which can be displayed or hidden one by one, being able to view information about individual elements of the map. It allows visual overlaying of vector and raster data with different reference systems, coordinates and servers.

Returning, in any case, a raster image in a widely used format, such as PNG, JPG or SVG, to the final user.

WMS specifies three operations (figure 1):

- GetCapabilities: Returns metadata to service level.
- GetMap: Returns a map image when geographical parameters and dimensions have been defined.
- GetFeatureInfo: Returns information with particular features shown on map.

1.1.2 WFS (Web Feature Service)

This is the standard that allows accessing and viewing to all the attributes of a spatial element, called feature, represented in vector mode, which geometry is described by a set of coordinates.

WFS specifies three operations:

- GetCapabilities: Retrieves the formal description or metadata of the service to determine available options.
- GetFeature: Performs the actual query by means of parameters such as bounding box and any other filters. The result is a group of data that contains geometry and asociated alphanumeric data.
- DescribeFeatureType: Retrieves the XML schema to allow the WFS client to parse the resultsets.

The data are provided in GML format (another OGC standard). A WFS allows not only to display the information as permitted by a WMS, but also the free view and download of the complete dataset.

1.1.3 WCS (Web Coverage Service)

Sometimes, geographical information is composed of values or properties describing spatial locations by means of a system of geographic coordinates, this is the so called Coverage. The GI can also contain temporary, regular or irregularly spaced information, as happens representing a Digital Elevation Model (DEM). The OGC defines Web Coverage Service to enable the recovery of geospatial data in the form of digital spatial geographic information coverages that represent phenomena of spatial variation in a representative way or as input data for scientific models.

This service is useful to consult digital elevation models and to calculate horizon lines. Operations defined in a WCS are:

- GetCapabilities: Metadata service and coverages offers.
- DescribeCoverage: Detailed description of hedging.
- GetCoverage: Get cover or part of it.

As mentioned, the DEM is the most important coverage in an archaeological SDI. As sources of MDE the recently released ASTER Global Digital Elevation Map (NASA, 2011) can be cited. It is formatted in 1 x 1 degree tiles as GeoTIFF file, covering the Earth's land surface between 83° N and 83° S latitudes, with an accuracy below 10m.

1.1.4 CWS (Catalogue Web Service)

The Web Catalog Service (CWS) is defined by the Open Geospatial Consortium (OGC) as interfaces to discover and query metadata about data. It enables requests for a diversity of information in terms of source and theme. These services are implemented using catalogue software as Geonetwork. It allows to discover all kind of IDE services as WMS or WFS using metadata from every service, dataset or layer.

Metadata are data about data. It is information and documentation making geographical data identifiable, understandable and sharable by users and other services. Metadata objetives are:

- Search for data sets, what data exits or are available in a certain area, for a given subject on a scale, a general date or specific features. Due to do this metadata stores information about the data set: what is said, why was prepared, when, who produced it and how, and so on.
- Choice between data sets, to compare different ones, so you can select which ones meet user requirements in a better way for the intended purpose.
- The use, describing technical characteristics of data, in order to allow efficient operation. It helps users both maintaining and updating these data.

Metadata must fulfill ISO 19115:2003 which describes the schema required for describing geographic information and services. This defines:

1. Mandatory and conditional metadata sections, metadata entities, and metadata elements.
2. The minimum set of metadata required to serve the full range of metadata applications (data discovery, determining data fitness for use, data access, data transfer, and use of digital data)
3. Optional metadata elements allowing more extensive standard description of geographical data and if required a method for extending metadata to fit specialized needs.

1.2 SDI components

Main SDI components are described in figure 2. These components allow the storage and distribution of geographical information.

- **File datasets**. The most common way to exchange geographical information in archaeology is using files. Sometimes these are open standard but the problem begins when data are stored using a propietary system. To ensure the availability of data between diferent services, software and users, data files must achieve OGC standards.

  DWG or DWF generated by AutoCAD, or Shapefiles, an ESRI widely used format are standards of this type. Sometimes a raster image can be used when it has been georreferenced. So we can use geoTIFF images or JPG and JGW files with information about projection, rotation and scale.
- **Spatial Database**. It stores the spatial elements and their attributes (Features). Some products are widespread as PostgreSQL PostGIS, Oracle Spatial or MySQL. These data are stored in tables using spatial indexes. There is a special language to create tables, select, update and delete records. This is Simple Feature Access for SQL (SFSQL) (OGC, 2011b). This allows to get spatial entities and represent them from an unique repository to any software.

- **Map Servers**. Software that allows publication of the maps and provide WMS and WFS services through Internet. Some examples are GeoServer and MapServer. Spatial datasets can be stored in Shapefiles, spatial databases or even georreferenced raster images. The servers allow additional operations such as layers reproduction, very useful in case of working with different reference systems. The different map servers characteristics are shown in table 1.

Name	Language	WMS	WFS	WCS
Spatial Fusion Server	Java/C++	Yes	Yes	No
ERDAS APOLLO	Java/C++	Yes	Yes	Yes
ArcGIS Server	.NET/Java	Yes	Yes	Yes
MapServer	C	Yes	Yes	Yes
Deegree	Java	Yes	Yes	Yes
GeoServer	Java	Yes	Yes	Yes
Basic-wms2.py	Pythom	Yes	No	No
Manifold System	ASP/C#	Yes	Yes	No
MapLarge API	C#	Yes	Yes	No
SpatialFX	Java	Yes	No	No
Orbit EOS	Java	Yes	No	No

Table 1. Main map servers. Adapted from OSGEO (OSGEO, 2011)

- **Desktops applications**. Traditional desktop applications that allow the processing of geographic data. In Archeology we are used to use Computer Aided Design (CAD) software such as Autocad to produce the traditional layers. But this can not generate standard information. Therefore, it is recommended to use other programs that generate geographic information in these formats. We have examples like gvSIG, UDig, QGIS or ArcGIS Desktop.
- **Thin Clients**. These applications are usually web clients, which allow viewing a small geographical and managing data from another possible data sources. These clients are created with API like Google Maps or OpenLayers. Its main utility is that can be used embedded in other applications and they can integrate information from different map services, both archaeological and other tematics.

All the elements in a SDI are represented only by a few components: Points, Lines, Polylines, Polygons and Raster data.

2. Archaeoastronomy

Since the beginning Archaeoastronomy has been developed by specialists of several and very different disciplines. This, added to the fact that it is a very young scientific branch, has caused a methodological and conceptual disorder. It can be seen, for example, in the variety of Archaeoastronomy definitions: *"Discipline which studies the way that ancient peoples' societies conected with the cosmos, taking into account archaeological, etnogrpahical and historical data"* (Cerdeño et al., 2006), *"Discipline which studies the degree of astronomical knowledges of past societies, connected with their vision of the cosmos"*(Belmonte, 2000) and *"Discipline which studies the development of astronomy of prehistoric societies inside their cultural context"*(Esteban, 2003).

Concerning to these lines, perhaps the best definition would be the science that studies the celestial landscape in the past taking into account any cultural data source such as

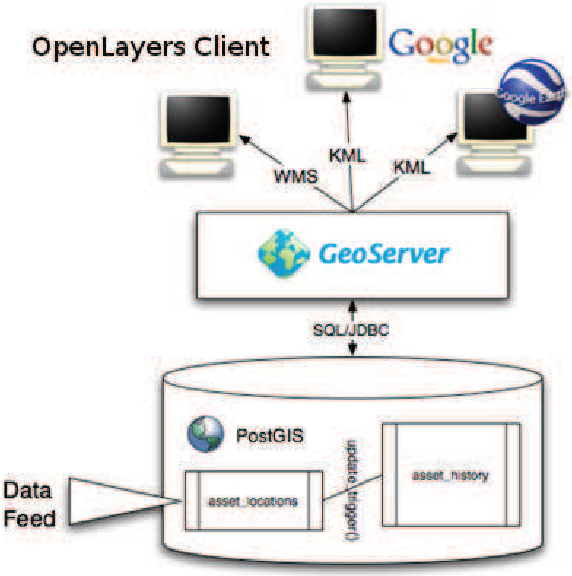


Fig. 2. Main SDI components (GEOSERVER, 2001)

archaeology, antropology, ethnography, historical data and so on. But in order to understand the situation in these days we should take a look of its beginnings.

The very first steps in the discipline were made by the interest of some people about the intentionated orientation of several megalithic monuments. These studies were made in XVIII century by the architect John Wood (Wood, 1747) and the antiquarian William Stukeley (Stukeley, 1740) related to Stonehenge, Callanish, Castle Rigg and Sarsen Circle. With these two first studies begins also two tendencies which remains nowadays. The first one is the predominant importance of megalithic studies in Archaeoastronomy against any other epoch archaeological sites (figure 3). The second tendency is related to the main role that british researchers had in this type of works.

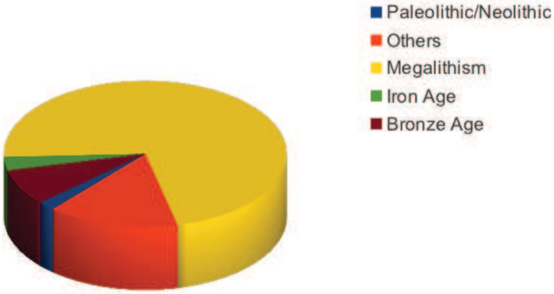


Fig. 3. Archaeoastronomical studies sorted by epoch. Based in (Cerdeño et al., 2006)

After Wood and Stukeley's contributions, the next remarkable work was made after the century change by another antiquarian, A.L. Lewis. It was a recopilation of archaeological sites with probable astronomical signification, which was used and extended by the British Army's Captain H.B. Sommerville and Sir Joseph Norman Lockyer (Lockyer, 1909).

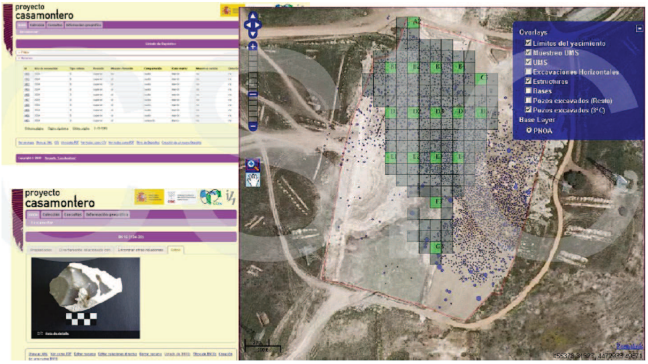
Alexander Thom is considered as the father of the modern Archaeoastronomy. His important publications "The solar observatories of Megalithic Man" (Thom, 1954) and "Megalithic sites in Britain" (Thom, 1967) are essentials in the bibliography. The main contribution of this engineer is applying topographical techniques and mathematical science to the study of different archaeological sites. Thom did not only based his research only in the traditional sites but kept studing only the megalithic ones.

With this new methodological approach the discipline reach to the 80's decade of the XX century. In this period the discipline spread in many european countries in some cases by the hand of researchers as Michael Hoskin and Carlos Jaschek who founded in 1992 the SEAC, (Sociétè Européenne pour l'Astronomie dans la Culture/European Society for Astronomy in Culture) to stimulate innovative concepts and methods that would serve to open up new understandings of the many and deep interactions between astronomy and culture. It was almost the only effort to get interdisciplinary works in Archaeoastronomy against traditional separated from archaeology ones.

2.1 Archaeoastronomy and Archaeology

The huge gap between natural and social sciences was a problem affecting to archaeoastronomical research, often this produced negative reaction between archaeologists in many cases rejecting astronomical conclussions. Afortunately it seems that, in the last few years, is changing with the appearance of some well designed interdisciplinary archaeoastronomical projects.

Archaeoastronomy can be seen as another archaeometry, the application of natural sciences techniques to the analysis of archaeological contexts. In this case, archaeoastronomy can handle inmaterial archaeological record, believes and ritualism interpretations unachievable with another point of view. The archaeologist will need a specialist to interpret astronomically an archaeological record. But, obviously, the cultural interpretations need an archaeologist who will discern between posible only astronomical interpretations.



Overlays
☑ Limites del yacimiento
☑ Muestreo UMS
☑ UMS
☐ Excavaciones Horizontales
☑ Estructuras
☐ Bases
☐ Pozos excavados (Resto)
☑ Pozos excavados (3ªC)
Base Layer
● PNOA

Fig. 4. WMS client example in Casa Montero archaeological project (Montero, 2003)

So, both sides are needed and essential, in any other case archaeoastronomical interpretations will be inexact or false; measurements without sense or archaeological contexts badly interpreted. Thus, we need interdisciplinary projects and researches feeding back each other to avoid that.

3. Spatial data infrastructure: Role in archaeoastronomical works

In archeology, the data traditionaly is stored in analogical format, only in the last few years archaeological information is appearing in digital format, mainly in DXF and DWG AutoCAD files. Analogical format carries some problems in geographical related projects, specially in Archaeology. The data is not easily shared between persons in different places being each person's work disconnected to the others work. The digital processing is somewhat complicated, having to digitalize each plane, if it is necessary, without the possibility of put the whole information together. In archaeological contexts, where the aim is getting as information as possible about human societies, this is specially important. As happens nowadays, we can not understand a society only with only one layer of information, for example, the religion. Information need to be together taking all human ancient societies aspects into account, including elevation, resources, soil utilization and astronomy (figure 5).

As a solution to this, the SDI is easily applied in archaeological research. Examples of this can be seen in figures 4 and 6. Systematically on each site, takes out a topographical reconstruction work. This involves making an inventory of all items that appear at the site, with the location information. The SDI, allows digital inventory of information, easily publicable in standard formats described above. All SDI are available via Internet, which making accesible information to different working groups in modern information society. Obviously, if necessary, it is possible to grant restricted access to the Cartographic Server based on the user role profile.

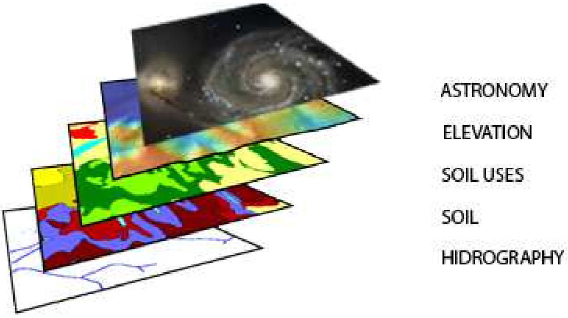


Fig. 5. Archaeoastronomical information as another layer of information in an SDI

To carry out the process of generating a digital inventory and publication in the SDI, some steps have to be perfomed:

- Land Survey. Using GPS, theodolites, technical photography and LIDAR data taken at the site. The GPS allows pinpointing each element in an archaeological site. This way, any building position can be taken, plotted or landscape elements can be mapped. LIDAR techniques has special interest, due to land reconstruction and performing high-precision DEMs. With airborne laser sensor -typically at rate of between 20,000 and 50,000 pulses per second- can reconstruct the whole field in study with centimeter accuracy. LIDAR and GPS gives georreferenced measures, so it is perfectly possible to generate the map. In each point the sensor picks up the echoes of the laser, measuring the height of each element of the terrain. The final result is a 3D model of the entire site.

- Spatial Database. The data collected are georreferenced and stored with its geographical location. Then stored in the database space.
- Geoprocessing. In most cases it is necessary to process this data (raw data). Depending on the work involved will be coordinate system transformation, change between representation styles, data crossing with other databases and SDIs, etc.
- Publication of the features. Finally we proceed to publish the vector data of the database server using the map. On it, as mentioned, images are generated to be used by different applications, showing the characteristic images of flatness and they can access the data of each object georeferenced.

How to use all this together with astronomical data? The solution comes from using data published by the Archaeological SDI through applications clients. The most helpful are the WMS and WFS. We can publish the astronomical data using two ways: Vector or Raster datasets.

The simplest way is to offer the data via GeoRSS GML format. This is a consistent standard in XML in which each element is associated with its geographical position. This option is better when we try to use a thin client, like OpenLayers and Google Maps. It uses a reduced bandwidth and increase time responses. It is very useful to represent separate elements, as the line of heliacal rising of a star or if we combine our archaeological layer with other vector and raster layers from other SDIs, such as geology, elevation model, etc. It is also possible use geoJSON. This is an open format to geoencoding different data structures. It is a more compact than geoRSS.

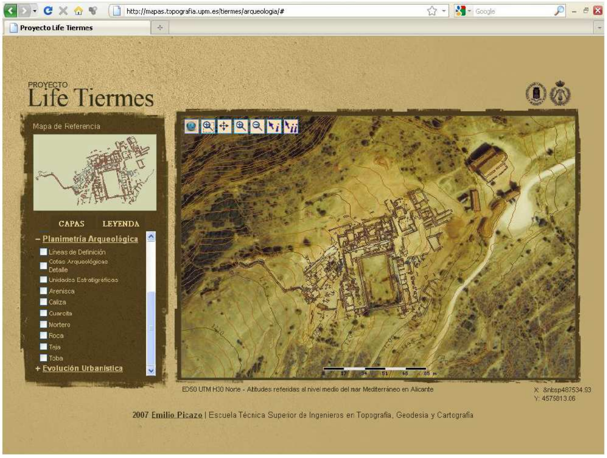


Fig. 6. SDI in Life Tiermes archaeological
http://www.mat.ucm.es/archaeoastronomy/project (Tiermes, 2007)

Another option is to generate a complete map layer, which could be stored in the database as raster or vector data sets and is published as a layer within the SDI. This solution is valid for representing lines such as northern and southern boundaries of an eclipse of the sun or near a transit visibility.

Using the user interface, the archaeologists can zoom into a selected region. Getting information is reduced to click on a layer element, even create new data or views mixing existing layers. Obviously all interest information can be downloaded to a local repository for later use.

3.1 Representing astronomical data

We have described the SDIs and what kind of information we can get from them, now we will focus on the astronomical data we have available and which are likely to be useful in historical studies. We will discuse:

- Heliacal rising of the bright stars and planets to determine alignments matches present in the mapping.
- Data on local circumstances in eclipses of the sun and moon, for dating historical events.
- Azimuth over the horizon of sunrise, sunset and passed the meridian of the Sun at the Solstices and Equinoxes.

3.1.1 Heliacal risings

In the case of heliacal Ortos, we will take into account the geometry described by Robert Purrington (Purrington, 1988). As a starting point, we need to have some knowledge about the profile that can be observed from a required position. To construct it, we can use a Digital Elevation Model (DEM) as basis. This consists in a file with a digital representation of the terrain's surface. For each X,Y position, an elevation value is given. There are several sources for this information, the most common used are satellite missions as SRTM or GETOPO30 (NASA, 2000). These projects provide free access to elevation models all over the world with different spatial resolutions and scales. From these files and the position of an observer, it is possible to reconstruct the profile of the horizon using any GIS software as gvSIG or QuantumGIS.

Next step is to determine the points of sunrise and sunset. To compute sun's or object position at any time on the horizon, we have to implement the following algorithm to ensure a good accuracy:

1. Apply correction for proper motion of the star.
2. Apply correction for precession.
3. Determine the date of the heliacal rising.
4. Apply refraction correction.
5. Calculate the azimuth of sunrise.

The result can be seen in the chart below, for each period, there is a shift in the position of azimuth on the horizon of this phenomenon, using the geometry of Purrington.

To determine the position of the heliacal point on rising to being able to represent the mapping, a whole set of software libraries can be developed that allow to apply this algorithm to remote dates from 4000 BC. For the calculations of precession we have applied the algorithm

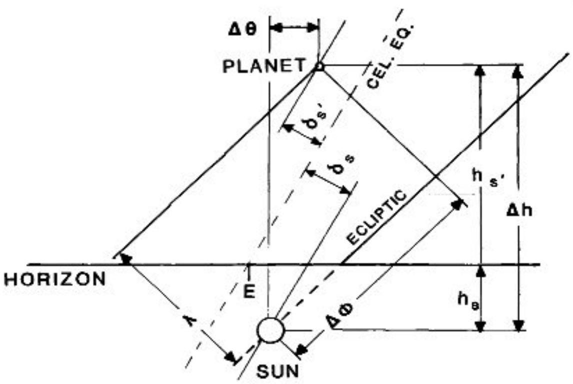


Fig. 7. Azimuth position shift by effect of the refraction. From (Purrington, 1988)

described by Gómez, J. (Gómez Castaño, 2006). And the method described in the latest edition of the Explanatory Supplement (USNO, 1992) for atmospheric refraction correction, see figure 7.

Among the objects observed by different civilizations are the Sun, the planets and some bright stars. In some cultures -e.g. egyptian culture-, the output of some stars, like Sirius, were taken as elements to indicate the beginning of the calendar. As a reference star positions and proper motions, the FK5 catalog (Fricke et al., 1991) can be used and the Bright Star Catalogue (Hoffleit & Warren Jr, 1991) for the positions according to the J2000.0 reference system.

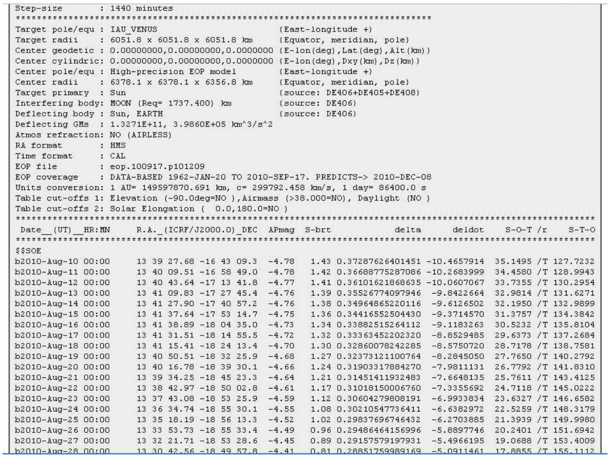
Concerning to the planetary positions in these times, the easiest source is the software using the JPL Horizons (figure 8). This provides for remote time, planetary positions using the JPL DE406 theory. It includes neither nutations nor librations. It is referred to the International Celestial Reference Frame. Time gap goes since JED 0624976.50 (-3001 FEB 04) to 2816912.50 (+3000 MAY 06). In any case we can develop customized applications from the coefficients of the theory. From the positions of the planets, the sun or the stars, the point on the horizon can be determined in which these stars appear or disappear. The azimuth of these points are plotted on a shape file or generates a vector layer which is distributed through SDI.

3.1.2 Alignments

Once those calculations get the ephemeris providing the Azimut of the Orto for every object, they have to be carried out to local times and places of archaeological site of interest. In the site, data are tested to get possible alignments. This can be achieved from a comparison between the astronomical layer containing rising and settings of the objects for a given date and the archaeological layer. Getting these layers into a SDI interface, the lines can aligned with terrestrial and architectonical elements.

3.1.3 Eclipses

On the other hand, for a given location historical events can be dated from the calculation of the local circunstances of an eclipse. This visibility can be calculated from the same besselianos elements of the eclipse. Recently, Fred Spenak has published Five Millennium Catalog of Solar



```
Step-size       : 1440 minutes
*******************************************************************************
Target pole/equ : IAU_VENUS                      {East-longitude +}
Target radii    : 6051.8 x 6051.8 x 6051.8 km    {Equator, meridian, pole}
Center geodetic : 0.00000000,0.00000000,0.0000000 {E-lon(deg),Lat(deg),Alt(km)}
Center cylindric: 0.00000000,0.00000000,0.0000000 {E-lon(deg),Dxy(km),Dz(km)}
Center pole/equ : High-precision EOP model       {East-longitude +}
Center radii    : 6378.1 x 6378.1 x 6356.8 km    {Equator, meridian, pole}
Target primary  : Sun                            {source: DE406+DE405+DE408}
Interfering body: MOON (Req= 1737.400) km        {source: DE406}
Deflecting body : Sun, EARTH                     {source: DE406}
Deflecting GMs  : 1.3271E+11, 3.9860E+05 km^3/s^2
Atmos refraction: NO (AIRLESS)
RA format       : HMS
Time format     : CAL
EOP file        : eop.100917.p101209
EOP coverage    : DATA-BASED 1962-JAN-20 TO 2010-SEP-17. PREDICTS-> 2010-DEC-08
Units conversion: 1 AU= 149597870.691 km, c= 299792.458 km/s, 1 day= 86400.0 s
Table cut-offs 1: Elevation (-90.0deg=NO ),Airmass (>38.000=NO), Daylight (NO )
Table cut-offs 2: Solar Elongation (  0.0,180.0=NO )
*******************************************************************************************************
 Date__(UT)__HR:MN     R.A._(ICRF/J2000.0)_DEC  APmag  S-brt            delta      deldot    S-O-T /r    S-T-O
*******************************************************************************************************
$$SOE
b2010-Aug-10 00:00     13 39 27.68 -16 43 09.3  -4.78   1.43 0.37287626401451 -10.4657914  35.1495 /T 127.7232
b2010-Aug-11 00:00     13 40 09.51 -16 58 49.0  -4.78   1.42 0.36688775287086 -10.2683999  34.4580 /T 128.9943
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b2010-Aug-13 00:00     13 41 09.83 -17 27 45.4  -4.76   1.39 0.35526774097946  -9.8422664  32.9814 /T 131.6271
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b2010-Aug-16 00:00     13 41 38.89 -18 04 35.0  -4.73   1.34 0.33882515264112  -9.1183263  30.5232 /T 135.8104
b2010-Aug-17 00:00     13 41 31.51 -18 14 55.5  -4.72   1.32 0.33363452202320  -8.8529485  29.6373 /T 137.2684
b2010-Aug-18 00:00     13 41 15.41 -18 24 13.4  -4.70   1.30 0.32860078242285  -8.5750720  28.7178 /T 138.7581
b2010-Aug-19 00:00     13 40 50.51 -18 32 25.9  -4.68   1.27 0.32373121100764  -8.2845050  27.7650 /T 140.2792
b2010-Aug-20 00:00     13 40 16.78 -18 39 30.1  -4.66   1.24 0.31903317884270  -7.9811131  26.7792 /T 141.8310
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b2010-Aug-22 00:00     13 38 42.97 -18 50 02.8  -4.61   1.17 0.31018150006760  -7.3355692  24.7118 /T 145.0222
b2010-Aug-23 00:00     13 37 43.08 -18 53 25.9  -4.59   1.12 0.30604279808191  -6.9933834  23.6327 /T 146.6582
b2010-Aug-24 00:00     13 36 34.74 -18 55 30.1  -4.55   1.08 0.30210547736411  -6.6382972  22.5259 /T 148.3179
b2010-Aug-25 00:00     13 35 18.19 -18 56 13.3  -4.52   1.02 0.29837696746432  -6.2703885  21.3939 /T 149.9980
b2010-Aug-26 00:00     13 33 53.73 -18 55 33.4  -4.49   0.96 0.29486464156996  -5.8897746  20.2401 /T 151.6942
b2010-Aug-27 00:00     13 32 21.71 -18 53 28.6  -4.45   0.89 0.29157579197931  -5.4966195  19.0688 /T 153.4009
b2010-Aug-28 00:00     13 30 42.56 -18 49 57.8  -4.41   0.81 0.28851759989169  -5.0911461  17.8855 /T 155.1112
```

Fig. 8. Ephemeris calculated with JPL's Horizons software

Eclipses -1999 to +3000 (Spenak & Meeus, 2009). These ephemeris are a important help dating historical events.

3.2 Using astronomical data in the archaeological SDI

At this point it is clear that the main advantage of using this tool is to encapsulate the complexity of astronomical calculations, providing only useful information for the archaeologist.

In this type of work it is necessary to take into account the time to which we refer our calculations. The archaeological sites correspond to a date in antiquity, or a period. The Earth is subject to precessional motion so we must take into account when ephemeris are generated (Vondrák et al., 2011). The archaeological community is not used to deal with this type of calculation, but it is possible to encapsulate it within the astronomical SDI and generate, this way, information that is integrated with the other layers. This makes it easy to use for the archaeologist.

To integrate the two types of information is useful to follow the following process:

1. From classical astronomical software commented before, we can calculate object possitions, taking into account the astronomical factors such as precession.
2. Ephemeris generation can be done on demand in real time or by storing ephemeris and serving sets as needed. These ephemeris are independent of the observing site.
3. Then, taking into account the position of the archaeological site corrections are made to include local factors such as atmospheric refraction, and calculating "local circunstances"
4. This ephemeris in vector format, lines, polylines or poligons, can be stored in spatial databases. It is also possible to generate shape files with the outcome of the ephemeris which can be added to the rest of archaeological GIS.
5. From the stored information in the database, a complete layer that is available to users through WMS or WFS can be generated. even downloadable in vector format if desired. It is also possible to publish data via GeoRSS and GML format to represent them in any kind of OpenLayers client or Google Maps.

The most important for the archaeologist is how to access these layers with astronomical information. To do this a client software is only needed to consume the services offered by the astronomical SDI. Any of the programs commonly used in archaeological can do that. It also can be developed customized programs based on thin clients, OpenLayers and the popular Google Maps that allows to user to integrate all kinds of layers and remote services with data stored locally.

Sometimes it can be useful the possibility of doing some geoprocesses with the information. As example, it can be useful the determination of the horizon visible from an archaeological site. Using the intended position of an observer and a DEM, the target profile shapefile is generated. These geoprocessing tools depend on the chosen program. There are very useful extensions like SEXTANTE (Olaya, 2011) or GDAL libraries (GDAL, 2011), open source software for Desktop or ArcGIS.

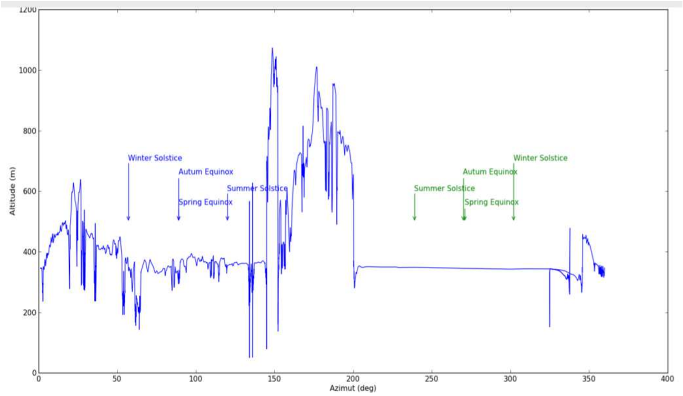

Fig. 9. Example of geoprocess. Horizon profile from Moreiros archaeological site at 4,000 B.C. (Mejuto et al., 2011; Valera & Becker, 2010; 2011)

As a result of applying these new layers to the existing archaeological and astronomical ones, a new tool for the analysis of the findings in archaeological sites appeared, and a line of knowledge about the culture of its inhabitants. The use of SDI allows to integrate these layers from astronomical servers, with the layers of the findings themselves.

4. Case study: Ditched enclosures in Portugal

The data used in this example have been achieved in the context of the project *Ditched Enclosures' plans and Neolithic Cosmologies: A Landscape, Archaeoastronomical and Geophysical Point of View.* This project is funded by Calouste Gulbenkian Foundation and scientifically leaded by the archaeologist Antonio C. Valera from Era Arqueología, the geophysical part was carried out by Helmut Becker from Becker Archaeological Prospections and the archaeoastronomical part was responsability of the authors (Valera & Becker, 2010; 2011).

The work involves Neolithic and Chalcolithic periods which are very interesting from an archaeological and astronomical point of view. Neolithic is a period of changes, very important and strong changes in some cases, as the transition to sedentary populations and the development of agriculture. It was also, an epoch of revolution in technology and minds. The ritualism, symbolism and social complex processes raised strongly.

Ditched enclosures are monuments with a tendency to circularity in shape with several concentric ditches from a few meters up to several hundred meters in diameter. Initial distribution was over a large part of Europe (specially in Germany, Austria, and Southern Britain) but nowadays we have an increasing number of this type of monuments all over Iberian Peninsula generally because of the civil works and a few of research projects.

We will take as example Moreiros site which is located in Arronches, Évora, with several enclosures some of them so called wavy enclosures. Usually the explanations of this type of sites have been referred more to group identity management or symbolic world distribution, putting the stress in the construction process itself as a social stimulator. Others just have seen in these sites a reflection of sedentary groups settlements in which typology talk us about hierarchy in the territory.

Methodology talking the aim is joining traditional GIS techniques with the astronomical ephemeris calculation and its representation over the landscape and terrain. We should stress the peculiarities of this study. The first one is that no one of the sites was never digged and the ditches are no structures that can be oriented. These aspects had to be solved by the work methodology.

On the one hand data gathering has been done on terrain including very precise GPS coordinates of each site. From UTM coordinates, we have made the calculation of the visible horizon from the site. After calculation we get a shape vectorial file that we can use with a Digital Elevation Model and the magnetic data.

The second part of the work is related to astronomical variables. In this example only the solar main positions are implemented. But it is perfectly possible to include some other lunar events, heliacal rises of stars, planetary events, asterism positions and so on. To get this we use a Python programmed code that give us another vectorial shape file as output which we can cross over the Digital Elevation Model again to get the astronomical orientations.

In figure 9 we can see one of the outputs of this software; this is the horizon profile from Moreiros at four thousand before Christ again with the solar main positions on it. In the horizontal axe the azimuth angles are displayed and in the vertical one the height in meters. At left in blue there are the rises and in the right the sets in green. It can be seen that, in this case, there are no topographic markers, astronomically speaking.

One of the other outputs of the software is the calculation of the azimuth angles of solar main positions all over the year. The final result can be seen in figure 10. In this case the sun main directions are shown: the summer solstice, the equinoxes and the winter solstice taking into account the topography. As you can see, the east door of the enclosure is oriented to winter solstice at the rise and the west door is oriented to the same event in the set. The shape of one of the enclosures is also related to the winter solstice as other structures marked with an arrow in the graphic.

This methodology has several interesting points, the technique used can be used in standard OGC services in internet as a way to outreach results of the research. Also gives us the possibility to study a site from different views (topoastronomy, orientation ...), everything with noninvasive techniques, Allowing us, in a simple way, getting geographical information useable in any other GIS tools where the astronomical information is another layer of information which can be served as other data in an archaeological project.

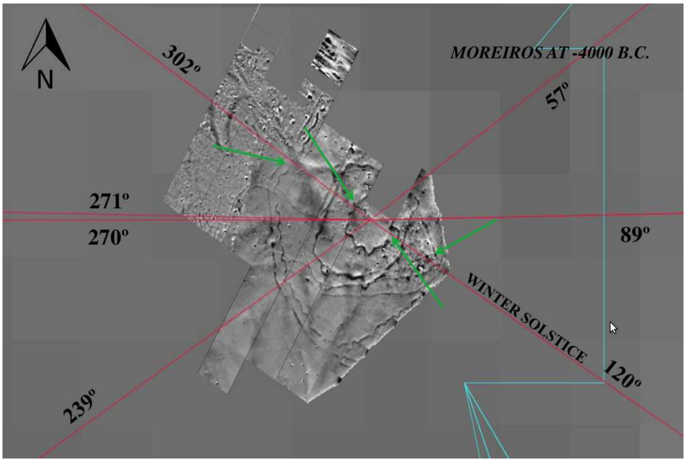

Fig. 10. Solar archaeoastronomical study for Moreiros at 4,000 B.C. As can be seen topography, landscape and geophysical data are considered (Mejuto et al., 2011).

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6. References

Belmonte, J. A. (2000). *Arqueoastronomía Hispánica. Prácticas astronómicas en la Prehistoria de la Península Ibérica y los archipiélagos balear y canario*, Equipo sirius.

Burrough, P. A. & McDonell, R. A. (1988). *Principles of Geographical Information Systems (Spatial Information Systems)*, Oxford University Press.

Cerdeño, M. L., Rodríguez, G., Moya, P. R., Ibarra, A. & Herrero, S. (2006). Los estudios de arqueoastronomía en españa. estado de la cuestión, *Trabajos de Prehistoria* 63(2): 13–34.

Esteban, C. (2003). La arqueoastronomía en españa, *Anuario del Observatorio Astronómico* pp. 309–322.

EU (2007). European INSPIRE directive.
URL: *http://inspire.jrc.ec.europa.eu/*

Fricke, W., Schwan, H., Lederle, T., Bastian, U., Bien, R., Burkhardt, G., du Mont, B., Hering, R., Jährling, R., Jahreiß, H., Röser, S., Schwerdtfeger, H. & Walter, H. (1991). Fifth fundamental catalogue (FK5). part 1. the basic fundamental stars, *Astronomisches Rechen-Institut* 32.

GDAL (2011). GDAL.
URL: *http://www.gdal.org/*

GEOSERVER (2001). Geoserver open source software project.
URL: *http://geoserver.org/display/GEOS/Welcome*

Gómez Castaño, J. (2006). Algoritmo de precesión válido para épocas remotas, *Astrum*.

Gómez Castaño, J., Mejuto, J. & Rodríguez-Caderot, G. (2011). Generación de una capa Astronómica para la IDE Arqueológica. Arqueoastronomía en el Sur de Portugal, *II Jornadas Ibéricas de las Infraestructuras de Datos Espaciales*.

Hoffleit, D. & Warren Jr, W. (1991). *The Bright Star Catalogue, 5th Revised*, Astronomical Data Center, NSSDC/ADC.

IGN (2011). Spanish national spatial data infrastructure (IDEE).
URL: *http://www.idee.es*

Lockyer, J. N. (1909). *Stonehenge and other British Stone monuments astronomically considered*, Macmillan and Co., Limited.

Mejuto, J., Valera, A., Gómez Castaño, J., Rodríguez-Caderot, G. & Becker, H. (2011). Ditched enclosures in southern portugal: an archaeoastronomical point of view of portuguese neolithic and chalcolithic, *Stars and Stones: Voyages in Archaeoastronomy and Cultural Astronomy - A meeting of different worlds*.

Montero, C. (2003). Casa montero archaeological project.
URL: *http://www.casamontero.org/*

NASA (2011). ASTER global digital elevation map 2.0.
URL: *http://asterweb.jpl.nasa.gov/gdem.asp*

OGC (2011a). Open geospatial consortium (OGC).
URL: *http://www.opengeospatial.org*

OGC (2011b). SFSQL standard.
URL: *http://www.opengeospatial.org/standards/sfs*

Olaya, V. (2011). SEXTANTE.
URL: *http://sextante.forge.osor.eu/*

Purrington, R. (1988). Heliacal rising and setting: Quantitative aspects, *Archaeoastronomy* 12.

Spenak, F. & Meeus, J. (2009). *Five millenium catalog of solar eclipses -1999 to +3000*, JPL-NASA.

Stukeley, W. (1740). *Stonehenge, a temple restor'd to the British Druids*.

NASA (2000). NASA's SRTM mission.
URL: *http://www2.jpl.nasa.gov/srtm/*

OSGEO (2011). Osgeo.
URL: *http://www.osgeo.org/*

Thom, A. (1954). The solar observatories of megalithic man, *Journal of the British Astronomical Association* 64: 396–404.

Thom, A. (1967). *Megalithic sites in Britain*, Oxford University Press.

Tiermes (2007). Life tiermes archaeological project.

USNO (1992). *Explanatory Supplement to the Astronomical Almanac*, University Science Books.

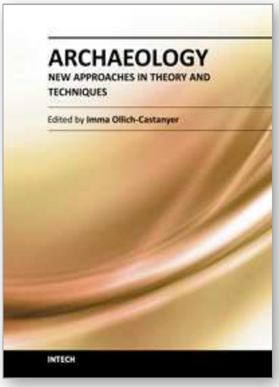
Valera, A. (2008). Mapeando o cosmos. uma abordagem cognitiva aos recintos da pré-história recente, *ERA Arqueologia* 8: 112–127.

Valera, A. & Becker, H. (2010). Arqueoastronomía, geofísica e recintos de fosos da pré-história recente no sul de portugal, *Actas do 8 Encontro de Arqueología do Algarve*.

Valera, A. & Becker, H. (2011). Cosmologia e recintos de fossos da pré-história recente:resultados da prospecção geofísica em xancra (cuba,beja), *Apontamentos de Arqueologia e Património* 7.

Vondrák, Capitane & Wallace (2011). New precession expresions, valid for long time intervals, *Astronomy & Astrophysics manuscript* .

Wood, J. (1747). *Choir Gaure, Vulgarly called Stonehenge, on Salisbury Plain*.



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