SEVENTH FRAMEWORK PROGRAMME	GLORIA is funded by the European Union 7th Framework Programme (FP7/2007-2013) under grant agreement n° 283783	

GLObal Robotic telescopes Intelligent Array for e-Science

The height of a mountain from its shadow (Total Lunar Eclipse 2014)

CODE:	DEL-091
VERSION:	02A
DATE:	April 2^{nd}, 2014

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Change Control

Issue	Date	Section	Page	Change Description
01.A	27/03/2014	All	All	First version
01.B	30/03/2014	All	All	Second version with additions and corrections
02.A	2/04/2014	All	All	Final version

Reference Documents

Nº	Document Name	Code	Version

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1. Objectives of the Activity

Through this activity we will learn how to measure the height of Mount Teide, the highest mountain in Spanish territory. To do this we'll take pictures during the lunar eclipse of April 15, 2014, when the projection of the shadow of Teide will be over the sea.
The objectives to be achieved are:

- Understand the nature of atmospheric phenomena, light rays and shadows.
- Calculate the height of a mountain from its shadow.

2. Instrumentation

Practical and numerical activities will be made using digital images taken from the Pico del Teide, Tenerife.

3. Phenomenon

3.1 Crepuscular and Anti Crepuscular rays

Crepuscular rays, in atmospheric optics, are rays of sunlight that appear to radiate from a single point in the sky, typically appearing in the clouds. In reality they are parallel and uniformly illuminated air columns separated by regions of shadow, generated by the clouds themselves. Although the rays are parallel, they appear to come from a point, the Sun, due to a perspective effect.

The name comes from their frequent occurrence during crepuscular hours (from the Latin *crepusculum*, dawn and dusk), when the contrast between light and dark areas is high.

Figure 1: Image showing the sun's crepuscular rays. Credit: J. C. Casado @tierrayestrellas.com

The Anti Crepuscular rays are similar and are generated in the same way as the crepuscular rays, but they are seen opposite to the Sun's position in the sky. As in the case of twilight, the anti crepuscular rays are parallel, but appear to converge to a point due to a perspective effect.

Because of their greater distance from the Sun, the anti crepuscular rays are weaker than the crepuscular ones.

Figure 2: Sunset showing anti crepuscular rays from the Altavista Refuge, Teide National Park, Tenerife. Credit: J. C. Casado @tierrayestrellas.com

3.2 Shadow of a Mountain

Like every other object, a mountain projects a shadow that is on the opposite side of it from the Sun. When the Sun is low on the horizon at dusk, the shape of the shadow initially reproduces the shape of the peak of the mountain. As time goes on, the length of the shadow grows as the height of the Sun decreases and its projection in the atmosphere ends up being triangular, regardless of the shape of the mountain peak. It is a perspective effect because you're really watching a vanishing point (see Figure 3). The finite size of the Sun also causes the umbral parts (fully shaded) of the shadow to converge and finally narrow in the distance. The Earth's shadow is more than a million miles long. For a high mountain it can be from 1 to 200 kilometers long. Thus, the triangular shadow can not be seen for small objects because the shadows they produce are not long enough.

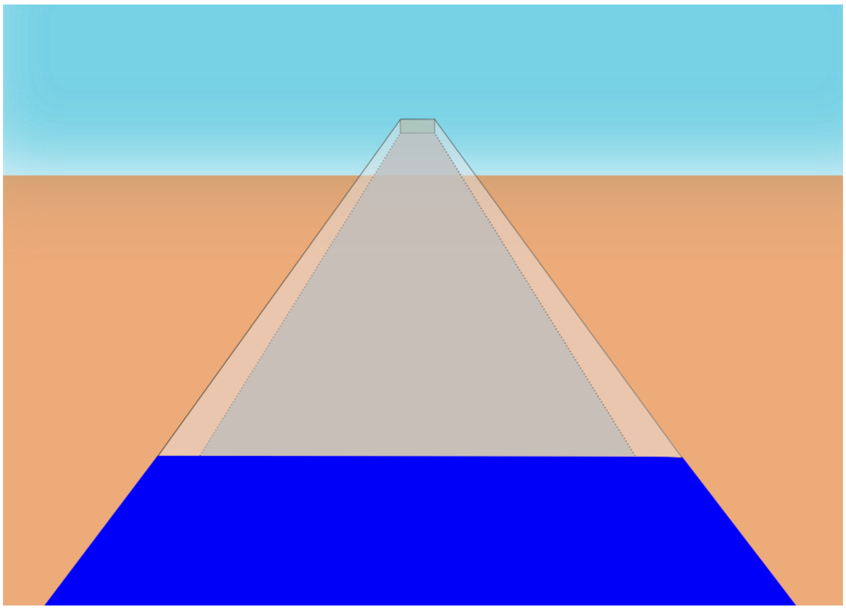


Figure 3: The view of the shadow, assuming a cubic mountain and looking from the top flat area. The perspective makes the cross-section immensely long with a triangular outline. Only at the far end of the shadow is the real shape of the mountain seen, but it is so far away and small that it is indistinguishable.

3.2.1 The Teide

The images that are used to perform this experiment are obtained using the Teide mountain.

The name 'Teide', comes from a Guanche (the ancient inhabitants of the islands) word and was originally called "Echeyde" or "Echeide". It is a volcano located on the island of Tenerife (Canary Islands, Spain). With an altitude of 3718 meters above sea level and 7500 meters above the ocean floor, it is the highest peak in Spain and of any landmass of the Atlantic Ocean. It is the third largest volcano on Earth if measured from its base on the ocean floor, after Mauna Kea and Mauna Loa, both on the Hawaiian islands. Teide's altitude also makes the island of Tenerife the tenth highest island in the world.

4. Practical Method

To do the experiment, the length of the shadow of the mountain on the ground is calculated using an image taken from the top of Teide close to moonrise on April 15, 2014. For the purposes of illustrating the method, a sample image, taken on February 14, 2014 near sunset (18:25 32 UT to be exact) is used (Figure 4).

Procedure:

From the image, the farthest point of the projection of the shadow on the Teide valley is determined.

Associate the tip of the projected shadow of the mountain with an easily identifiable geographical feature in the image - one that can be easily identified again later (see *Punto A* in Figure 4).

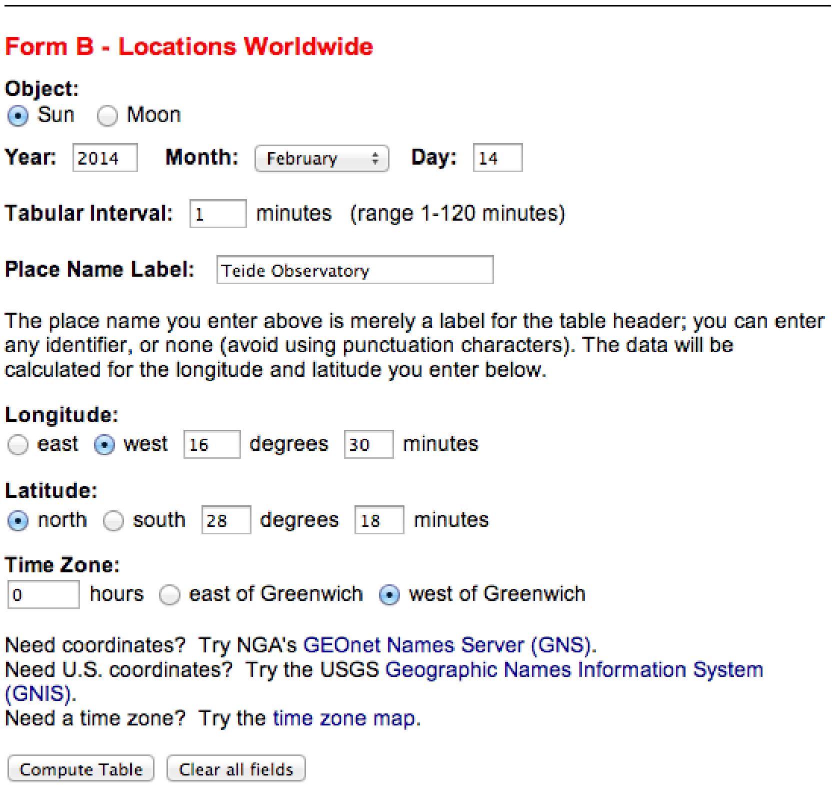
Download and install the tool 'Google Earth' on your computer (**ref1**). Once installed, run it and find (field to be filled in on the upper left) the mountain "Teide, Santa Cruz de Tenerife", so that the tool will zoom in on and land right on top of the mountain. Google Earth requires an Internet connection to run properly.

Using the mouse, search in the image for the reference point that was previously identified in the image (point A in Figure 4), keeping the same image perspective, or as close as possible to it.

Once identified, click on the ruler tool located at the top of the interface and then measure in the map the distance between that point and the peak of Teide. A small window will appear that will give the distance between points in the units of choice. In this case, select kilometers. This distance is called *S*. Also note the height of the reference point (if it is unknown), which is called h_a below (Figure 6).

Now that the distance between the reference point and the peak of Teide is known, the next step is to find out the height of the Sun above the horizon for the day and time when the picture was taken. There are several tools on the web to do this (e.g. **ref2** and **ref3)**. For this example, the website of **ref3** is used (Figure 5) to obtain a chart of the height and azimuth of the sun throughout the day. Only the height (called 'altitude') is needed for the experiment.

Figure 4: Image taken to illustrate the method



Form B - Locations Worldwide

Object:
Sun Moon

Year: 2014 **Month:** February **Day:** 14

Tabular Interval: 1 minutes (range 1-120 minutes)

Place Name Label: Teide Observatory

The place name you enter above is merely a label for the table header; you can enter any identifier, or none (avoid using punctuation characters). The data will be calculated for the longitude and latitude you enter below.

Longitude:
east west 16 degrees 30 minutes

Latitude:
north south 28 degrees 18 minutes

Time Zone:
0 hours east of Greenwich west of Greenwich

Need coordinates? Try NGA's GEOnet Names Server (GNS).
Need U.S. coordinates? Try the USGS Geographic Names Information System (GNIS).
Need a time zone? Try the time zone map.

Compute Table Clear all fields

Figure 5: Form from the **ref3** website. By filling in the various fields mentioned in the text a data table of the positions of the sun on the given date is returned. To perform this activity using images taken from Teide it is not necessary to change the values that appear in Longitude and Latitude. Only the date and time need to be modified to match the day of interest. Also note that Canary Islands use daylight saving time during summer, so that during winter time the difference between local time and UT is 0, but in summer time the difference between local time and UT is 1 hour.

In this case, the image was taken at 18:25 UT, and looking at the results from the **ref3** site, the corresponding height (altitude) was 5.8 degrees above the local horizon (called α).

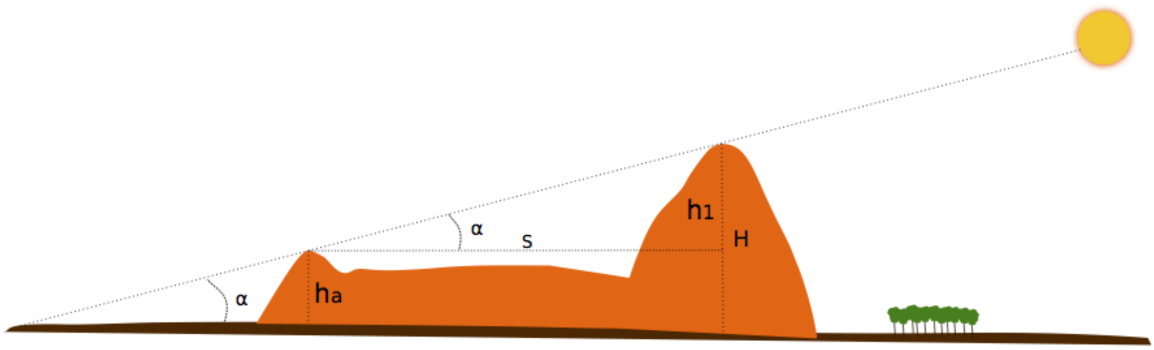


Figure 6: Diagram showing the different elements in the formula.

Using the formula defining the tangent of an angle, the value of the height h_1 can be calculated (Figure 6). This corresponds to the height of the mountain as viewed from Point A.
To calculate the total height H, h_1 must be added to the value of the height of Point A (h_a). In short:

$$\tan \alpha = h_1 / S \Rightarrow h_1 = S \cdot \tan \alpha \Rightarrow H = h_1 + h_a$$

Then putting values in from the image, S = 13.72 km and α = 5.8 °. The value of h_a in the example is about 2.35 km, and substituting we obtain that H is:

$$\tan \alpha = h_1 / S \Rightarrow h_1 = 13.72 \text{ [km] x } \tan 5.8° = 1.394 \text{ [km]} \Rightarrow H = 1.394 + 2.35 = 3.74 \text{ [km]}$$

The actual height of Teide is 3.718 km, in good agreement with the value obtained.

REFERENCES

ref1. Google Earth web page (http://www.google.com/earth/).
ref2. Web site to search for the position of the Sun in the sky for a given date, and more. (http://www.sunearthtools.com/dp/tools/pos_sun.php?lang=en).
ref3. Web site to search for the position of the Sun (http://aa.usno.navy.mil/data/docs/AltAz.php).
ref4. REYNOLDS, M.D. and SWEETSIR, R.A.: *Observe eclipses*. Observe Astronomical League Publications, Washington (USA), 1995. *Sky and Telescope*, *Sky Publishing Corporation*.
ref5. Lunar eclipse preview. Fred Espenak (2012) (http://www.mreclipse.com/Special/LEnext.html).
ref6. Wikipedia. (http://es.wikipedia.org/wiki/Eclipse_lunar).
ref7. USNO Portal website on eclipses, a reference on the subject. Contains maps and catalogs of past and future eclipses (http://aa.usno.navy.mil/data/docs/UpcomingEclipses.php).
ref8. Wikipedia. History of the Lunar observation in Spanish and Catalan (http://es.wikipedia.org/wiki/Historia_de_la_observación_lunar).

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