

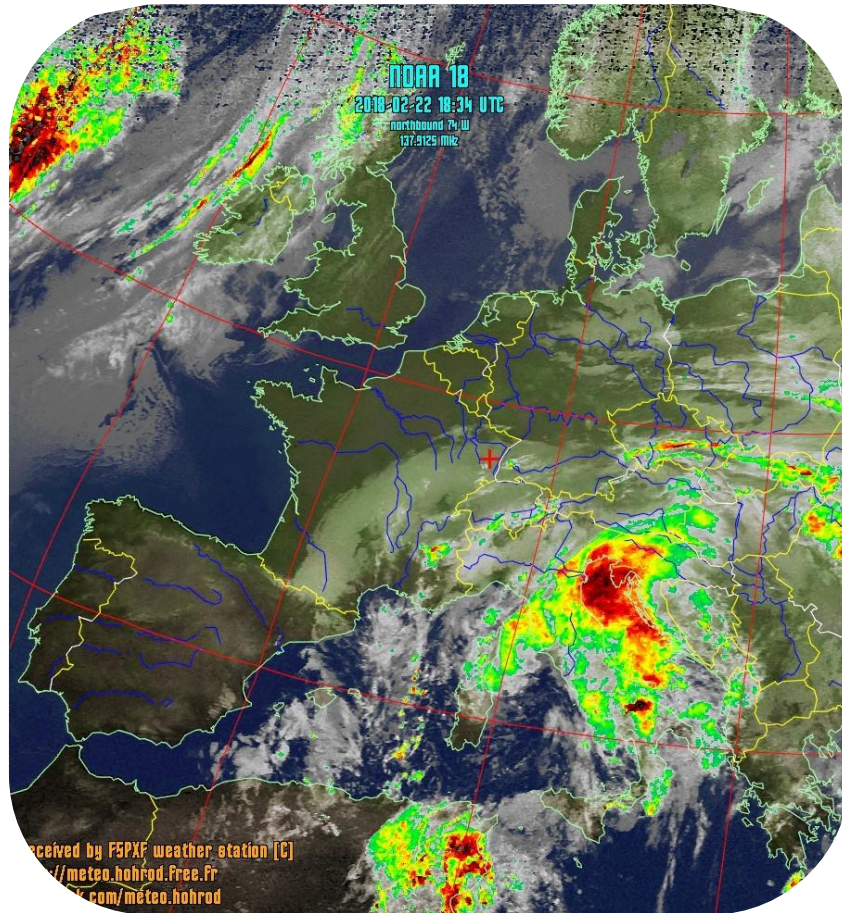


CESAR Science Case

# Decoding Signals from the Sky

## How do satellites communicate with the Earth?

Teacher guide



*NOAA 18 Northbound 74° W on 137.9125MHz, MCIR with Precipitation Enhancement, Normal Projection, Channel A: 3 (Mid Infrared), Channel B: 4*





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## Fast Facts

### FAST FACTS

**Age range:** 14-16

**Type:** Student activity

**Complexity:** Medium

**Preparation time:** 1 hour

**Lesson time required:** 1 hour

**Location:** Indoors

**Includes use of:** Computers

### Curriculum relevance

#### Mathematics

- Polar and spherical coordinates.
- Geographical coordinates and time zones. Longitude and latitude.

#### Geography and History

- Earth representation. Longitude and latitude.
- Climates and their geographical division.
- Maps and other cartographic representations.

#### Technology, programming and robotics

- Signals and communication systems.

### Students should already know...

1. The basic characteristics of an orbit.
2. The polar and spherical coordinates.
3. The concepts of longitude and latitude.
4. The basic concepts of signals and communication systems.

### Outline

In this activity, students make use of simple software tools to predict the pass of a weather satellite and to decode and interpret a message sent by it.

### Students will learn...

1. Different orbits satellite use.
2. How to decode a satellite's signal.
3. The information that weather satellites provide to study the climate.

### Students will improve...

- Their teamwork and communication skills.
- Their ability to apply theoretical knowledge to real-life situations.
- Their skills in the use of ICT.

### You will also need...

- Tool to predict passes of satellites.
- Tool to visualise signals of satellites.



## Summary of activities

Title	Activity	Outcomes	Requirements	Time
1. Hypothesis	Students will use a software package to predict a satellite pass over the ground station and the concepts of <i>visibility</i> , <i>acquisition/loss of signal</i> and different coordinate systems.	Students improve: <ul style="list-style-type: none"> <li>• Their understanding of scientific thinking</li> <li>• Their strategies of working scientifically</li> <li>• Their teamwork and communication skills.</li> </ul>	None	5 min
2. How do we know which frequencies can be detected by an antenna?	Students explore the file using standard software to visualise the audio signal received from the satellite.	Students learn: <ul style="list-style-type: none"> <li>• How satellites communicate to Earth.</li> </ul> Students improve: <ul style="list-style-type: none"> <li>• Their evaluation skills.</li> <li>• Their skills in the use of ICT.</li> </ul>	None	10 min
3. Plan contact with a satellite	Students use a software tool to decode the audio signal received from the satellite to convert it into a weather image.	Students learn: <ul style="list-style-type: none"> <li>• What information can be seen and extracted from a weather audio signal.</li> </ul> Students improve: <ul style="list-style-type: none"> <li>• Their teamwork and communication skills.</li> <li>• Their skills in the use of ICT.</li> </ul>	Use of <i>gpredict</i> software	15 min



Title	Activity	Outcomes	Requirements	Time
<p>4. <i>Interpret a signal from the sky (of a weather satellite)</i></p>	<p>Students use different image enhancements provided by the software to add false colours to the image to help analyse the information.</p>	<p>Students learn:</p> <ul style="list-style-type: none"> <li>• What information can be seen and extracted from a weather image.</li> </ul> <p>Students improve:</p> <ul style="list-style-type: none"> <li>• Their understanding of scientific thinking.</li> <li>• Their strategies of working scientifically.</li> <li>• Their teamwork and communication skills.</li> <li>• Their ability to apply theoretical knowledge to real-life situations.</li> <li>• Their skills in the use of ICT.</li> </ul>	<p>Use of <i>WxtolImage</i> software</p>	<p>25 min</p>



## Introduction

### The European Space Agency

The European Space Agency (ESA) is an international organisation focused on the development of the Space sector, using Europe's spatial capacity to the fullest, and on making sure that the investment made on Space is for the benefit of every citizen of Europe and the World. The European Space Agency comprises 22 member states that cooperate to carry out programs and activities more valuable than those executable by a single country.



Figure 1: Centres of the European Space Agency. (Credits: ESA)

The European Space Agency consists of various centres, each one of them with a specific mission. The main ESA centres are: ESA Headquarters (Paris, France), ESTEC (Space Research and Technology Centre in Noordwijk, Holland), ESOC (Space Operations Centre in Darmstadt, Germany), ESRIN (Space Research Institute in Frascati, Italy), ESAC (Space Astronomy Centre in Madrid, Spain), EAC (Astronaut Centre in Cologne, Germany), ESEC (Space Security and Education Centre in Belgium) and ECSAT (Centre for Space Applications and Telecommunications). We also have to mention the launch centre that ESA owns in Kourou (French Guiana), as well as a series of antennas across the whole globe, as can be seen in Figure 2.



Figure 2: Tracking antennas used by ESA. (Credits: ESA)

## Artificial satellites: Why do we need them?

Artificial satellites are those built by humans. These allow us to maintain communication between different places in our planet (telecommunications satellites), study the meteorological conditions of a region (weather satellites), as well as observe other planets in the Solar System, the Sun and other stars in our galaxy (The Milky Way) and other galaxies. The reasons why these observations cannot be performed with telescopes or sensors on Earth might be that they need to be closer to the objects being measured (close to Mars, like Mars Express and ExoMars), that they need a wider view from more elevated zones of the atmosphere (Meteosat, NOAA, Galileo system), that the processes being studied are not visible from the Earth because their light is absorbed by the atmosphere or that tests need to be done at different gravity conditions than on Earth (International Space Station).

## How do we communicate with satellites?

To communicate with a satellite we need at least the components shown in Figure 3:

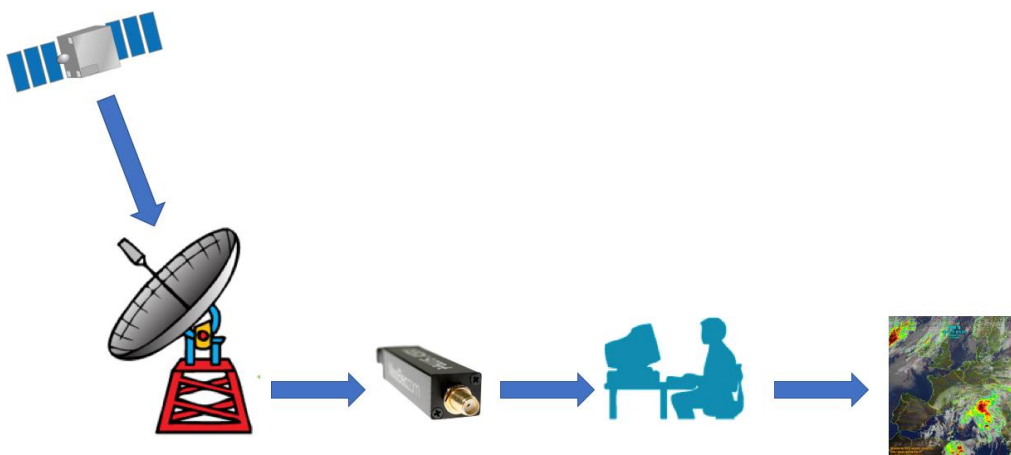


Figure 3: Communications reception system. (Credits: ESA)





- **Satellite:** In charge of performing a mission and placed in an orbit for it. Among its components these two, with their sub-components, should be highlighted:
  - **Service module or platform:**
    - *On board computer:* controls each piece of the satellite by software.
    - *Telemetry subsystem:* prepares the information of the platform and useful load in the corresponding emitted signals.
    - *Source of power:* generally generated by the Sun and collected by solar panels. This is stored in the battery.
    - *Propulsion system:* generally regulated by hydrazine tanks.
    - *AOCS (attitude and orbit control system):* ensuring the satellite points in the right direction by using sensors like star trackers, which recognise star patterns in the sky, and actuators, like reaction wheels to control momentum.
  - **Useful load:** Depending on the mission goal, these might be telescopes, cameras or magnetometers. Instruments that are more complex can have their own computer with command controls, thermal or voltage sensors, etc.
- **Antennas (or ground stations):** Both on board of the satellite and in land, they are in charge of transmitting and receiving the information (the signal). The signal can contain instructions for the satellite (called *telecommands*) or the executed measurements (called *telemetry*). The antennas consist of :
  - *Transmitter:* amplifies and modulates\* a signal.
  - *Receiver:* amplifies and demodulates (the opposite of modulate\*) a signal and filters the noise and the interference.

Each antenna has an effective area with which it is capable of receiving the information of a satellite that passes above it. This is called *antenna coverage*.

## Description of the activities

This science case introduces some aspects related to satellites: **communications** and **antennas**.

Throughout this activity, students will use different software tools (all of them with free licence) to predict the passes of a satellite (using **gpredict**) and decode the signal received from a weather image (using **Wxtoimage**).

### Activity 1: Hypothesis

1. What information about a satellite do you think is needed to find it and communicate with it?

Its **orbit** or the position of the satellite at every moment. The projection of the trajectory of the satellite on the terrestrial plane receives the name of trace. It is also necessary to know the **band** or wavelength at which the satellite emits to know if my antenna is able to receive the signal.

2. Do you think that there is any satellite that is always visible from the same point on Earth? If the answer is yes, what characteristics should it have for that to be the case?



**Geostationary satellites** could be seen from Earth at the same position in the sky. The reason is these type of satellites have *the same rotation period as the Earth*, to be precise a **sidereal day**<sup>1</sup>, which is slightly shorter than the civil day of 24 h, being 23 h 56 min 4.1 s

### Did you know?

Like a CubeSat in a low orbit, satellites can trace various types of orbits, which produce different projections on the map of the Earth. In Figure 4, we can see the traces that would be shown by the orbit of a satellite like CubeSat. We observe that the trace's pattern is repeated in time with a fixed displacement, which is caused by the rotation of the Earth in that time.

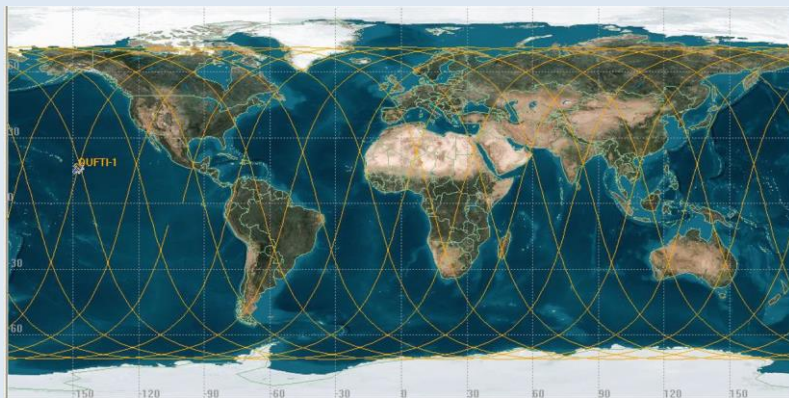


Figure 4: Trace of a satellite like CubeSat OUFTI-1 on the Earth's map. (Credits: ESA)

### Did you know?

The frequency and the wavelength of electromagnetic waves are related to the medium in which they travel. If we were on empty space, they would move at the speed of light ( $c = 300\,000\,000\text{ m/s}$ ) and their relationship would be

$$c = \lambda\nu$$

where  $\lambda$  is the wavelength,  $\nu$  is the frequency and  $c$  is the speed of light.

<sup>1</sup> **Sidereal time** is a "time scale that is based on [Earth's rate of rotation](#) measured relative to the [fixed stars](#)".<sup>[1]</sup> Viewed from the same [location](#), a star seen at one position in the sky will be seen at the same position on another night at the same sidereal time.

## Activity 2: How do we know which frequencies can be detected by an antenna?

The CubeSat antennas in ESAC are attached to a **receiver**, which is based on software. This type of receiver is called SDR (**Software Defined Radio**) and it means that the software in an integrated circuit has substituted a big part of the hardware in the receiver. The SDR is **connected** by a USB port **to a computer** where the signal decoding takes place to see the final image.

The CESAR initiative has two antennas that are 70 cm and 2 m long installed in ESAC, where other tracking antennas are set up for several ESA scientific missions.

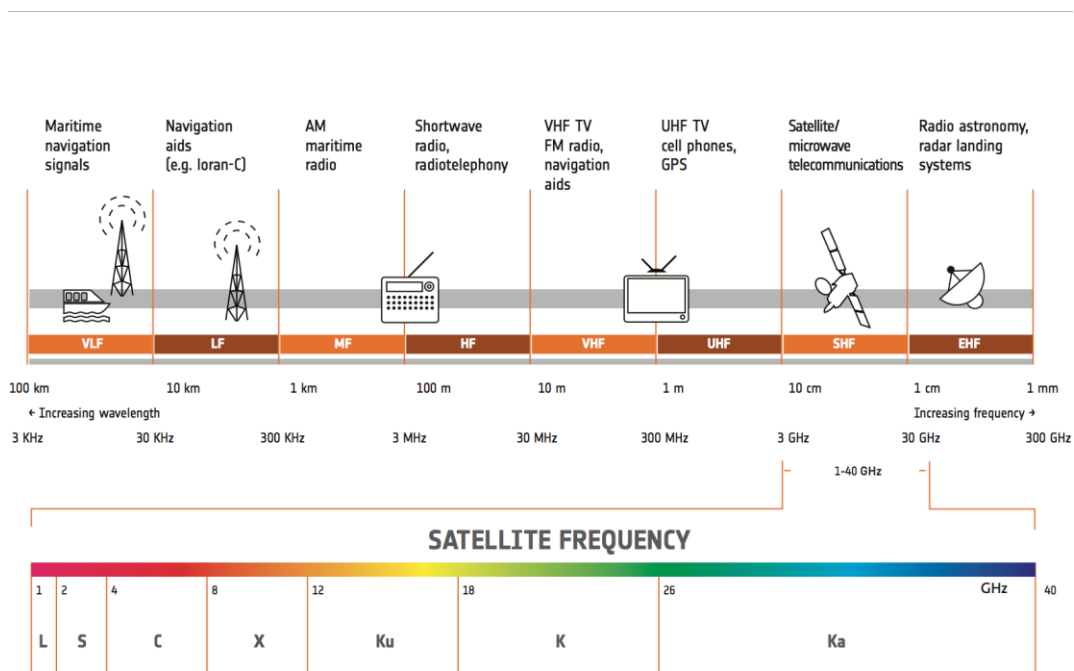


Figure 5: Frequency bands employed by satellites of the ESA. (Credits: ESA)

Take a look at Figure 5 and answer the following questions:

- What is the name given to the spectrum bands at which the antennas transmit/receive signals?
  - 70 cm antenna (UHF)
  - 2m antenna (VHF)
- Which everyday devices can interfere with the antennas?
  - 70 cm antenna (UHF) - TV, cell phones, GPS
  - 2m antenna (VHF) - TV, radio, navigation aids in general



3. Simplifying the situation to signals travelling through the empty space, which frequencies would be transmitted/received by the antennas?

The main frequency at which an antenna emits/receives can be derived from the equation that connects wavelength with frequency. Therefore:

- For a 70 cm antenna, band UHF, the main frequency of emission/reception is:

$$\nu = \frac{c}{\lambda} = \frac{300\,000\,000\text{ m/s}}{0.7\text{ m}} = 428\,571\,428\text{ s}^{-1} = 428\text{ MHz}$$

- For a 2m antenna, band VHF, the main frequency of emission/reception is:

$$\nu = \frac{c}{\lambda} = \frac{300\,000\,000\text{ m/s}}{2\text{ m}} = 150\,000\,000\text{ s}^{-1} = 150\text{ MHz}$$

### Activity 3: Plan contact with a satellite:

#### Step 1: Getting to know the *gpredict*<sup>2</sup> software

In this activity, you will use a software tool (called *gpredict*) to predict the satellite passes over a specific Earth location.

1. You will work with the screen configuration shown in Figure 6.

If it does not appear by default when opening the tool, you can select it following the steps:

***Edit → Preferences → Modules → All views (wide).***

You might need to restart the tool afterward to load this view.

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<sup>2</sup> <https://github.com/csete/gpredict/releases/download/v2.2.1/gpredict-win32-2.2.1.zip>,  
<http://gpredict.oz9aec.net/>

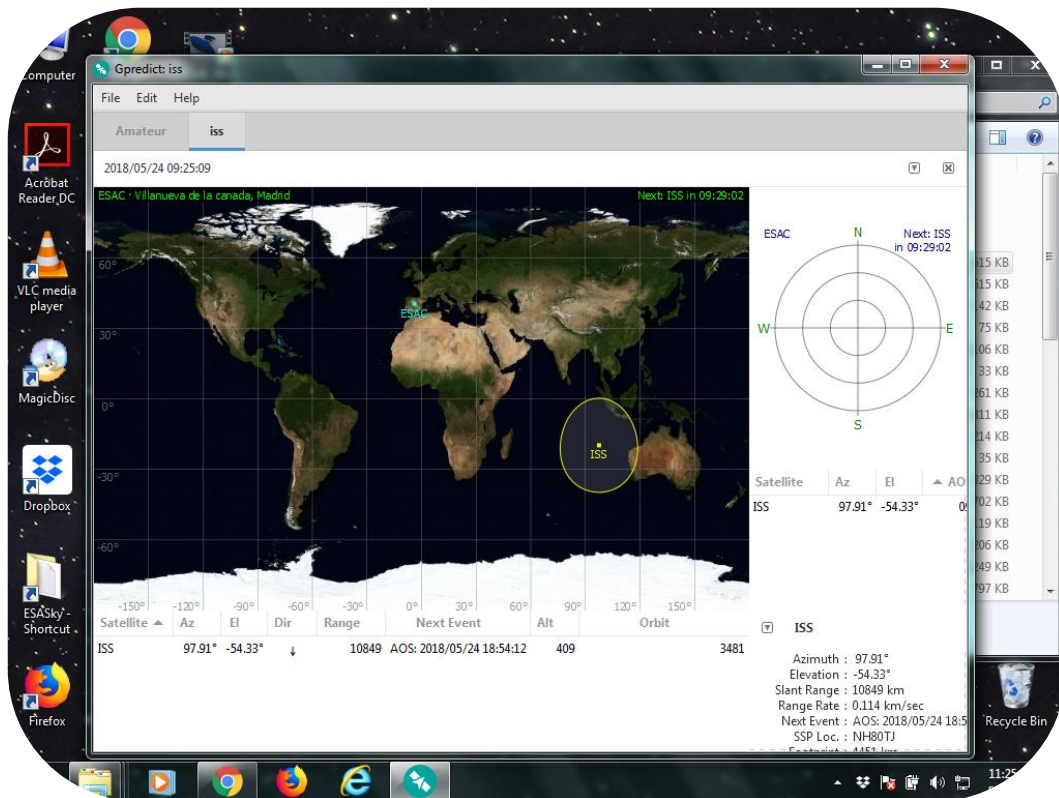


Figure 6: Main window on gpredict. (Credits: CESAR)

Define the location of the station you are planning to use to follow a satellite from Earth. In our example, we have used the coordinates of the European Space Astronomy Centre, close to Madrid.

2. Look for the coordinates on Google Maps and write down the results in Table 1.

Table 1: ESAC coordinates.

Location	Latitude	Longitude	Altitude
Villanueva de la Cañada	40.4440°	3.9530°	607 m

If you want, you can also use your school or house as your ground station.

Register the *longitude*, *latitude* and *altitude* information by following these steps (Figure 7):

**Edit → Preferences → General → Ground stations → Add new → Latitude, Longitude, Altitude**

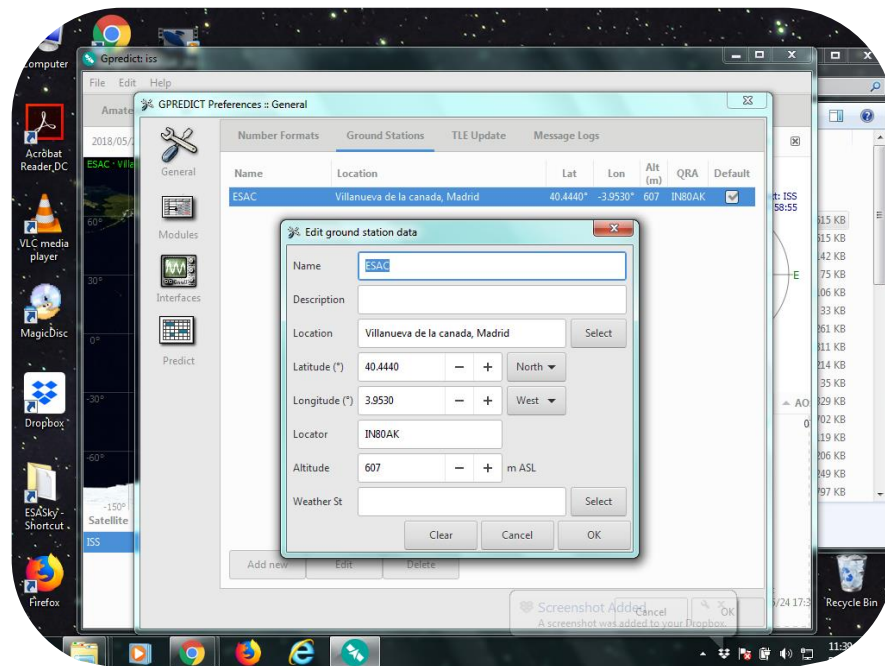


Figure 7: Configuration of the ground station location on gpredict. (Credits: CESAR)

3. Define the limits of the antenna for the satellite tracking, taking into account that, in general, the **minimum height** to which the antenna must point for the pass of the satellite is about **20 degrees above the horizon**, so that buildings or trees are avoided (Figure 8):

**Edit → Preferences → Predict → Pass conditions →**

**Minimum elevation = 20 deg**

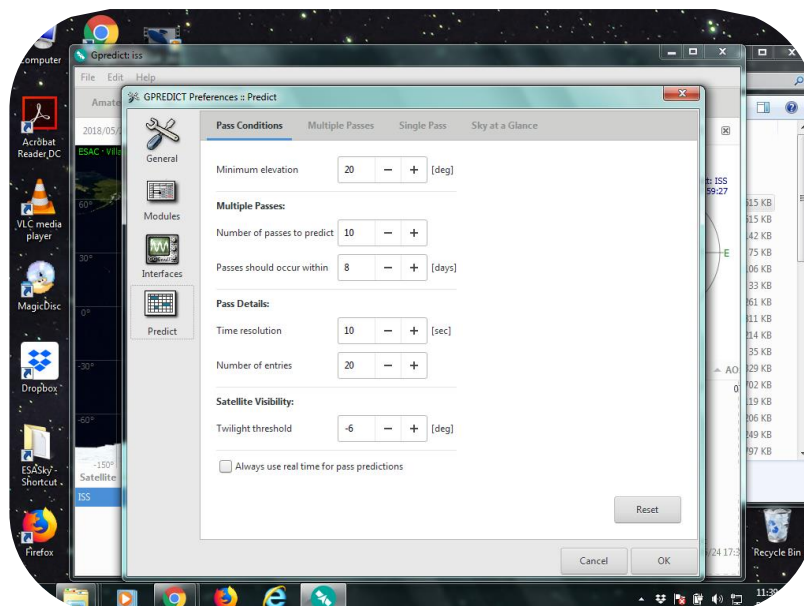


Figure 8: Defining the limits of the antenna on gpredict. (Credits: CESAR)



4. Now you can study the visibility of satellites from your ground station. Look for the satellites that you find interesting and add them to the favourites list, following these steps (Figure 9):

**Dropdown menu at the right upper corner → Configure →  
Satellite you want to add → Add satellite to list (Arrow pointing to the right)**

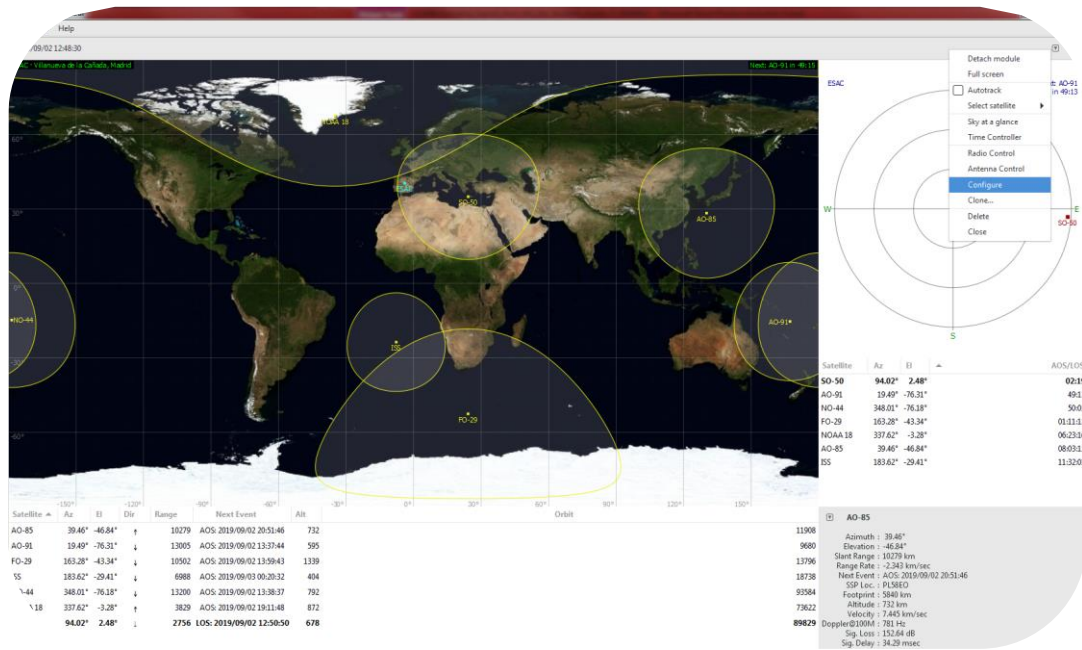


Figure 9: How to configure the list of selected satellites on gpredict –step 1. (Credits: CESAR)

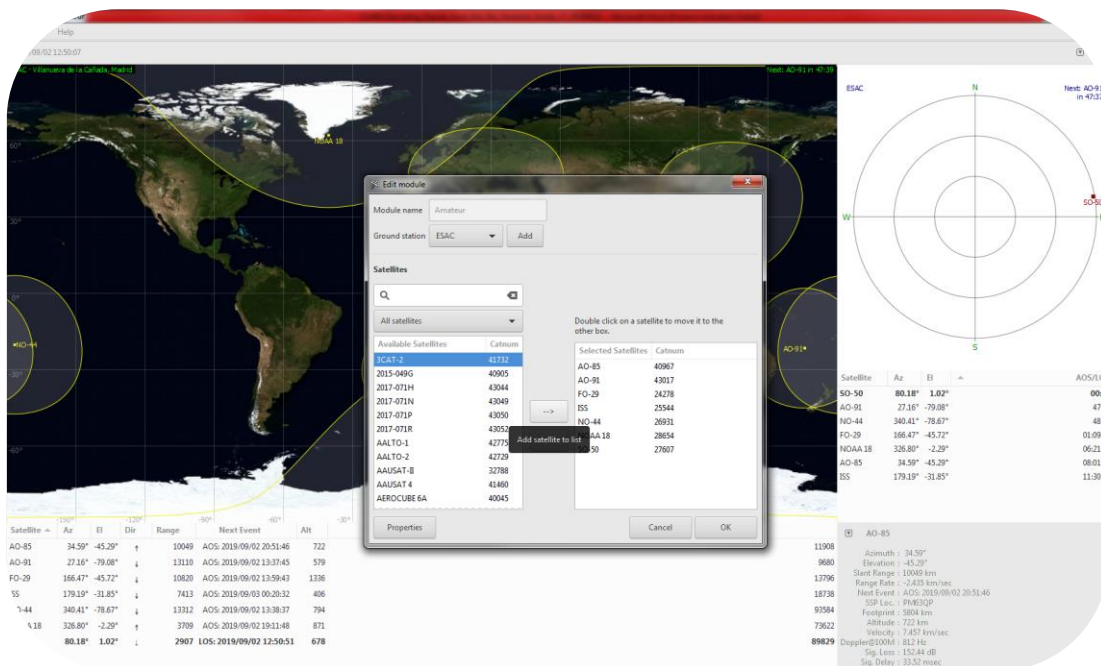


Figure 10: How to configure the list of selected satellites on gpredict –step 2. (Credits: CESAR)



- Right click on the **satellite NOAA 18** and check when the next pass over your location is (*show next pass*). A pop-up window will open with the data of this satellite (Figure 10).

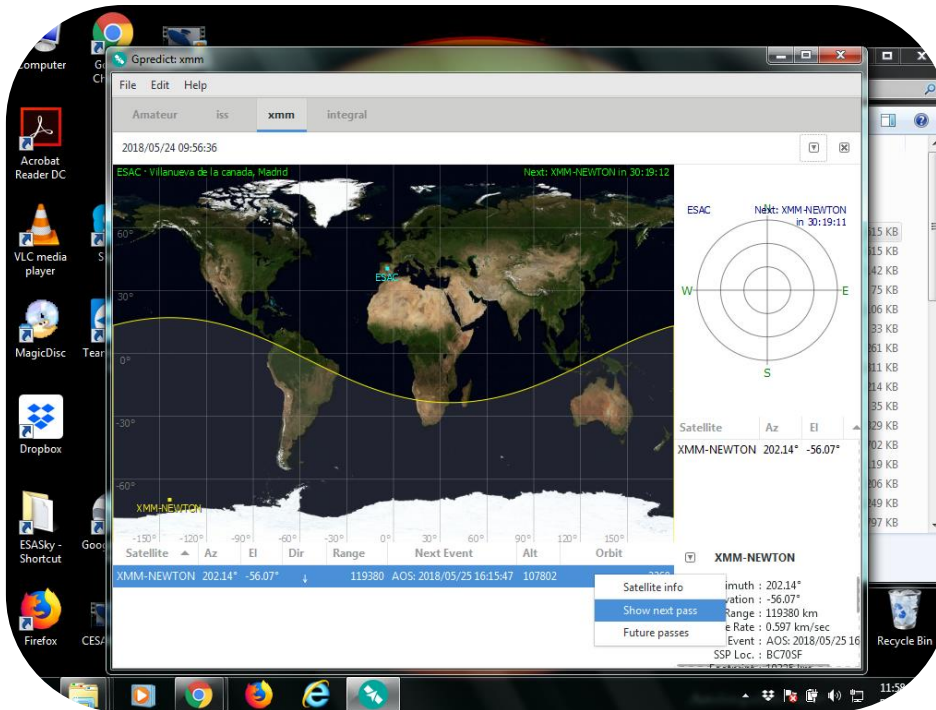


Figure 10: Looking for information about the satellite and determining the next pass on gpredict. (Credits: CESAR)

## Activity 4: Interpret a signal from the sky (of a weather satellite)

### Step 1: What is an audio file?

Discuss with the students how to see the contents of an audio file and listen to it. Let them explain what an audio file is and deduce why they are used to transmit data.

### Step 2: What does an audio file look like?

Discuss with the students what is necessary to build an image: *coordinates in pixels* (number of pixels) and *intensity* (in grey scale).

Audio file used for this activity: *090729 1428 noaa-18 8bit.wav*





### Step 3: Getting to know the *Wxtolmage*<sup>3</sup> software

In this activity, you will use a software tool (called *Wxtolmage*) to inspect weather satellite data.

You will set up the software as indicated from Figures 11 to 18.

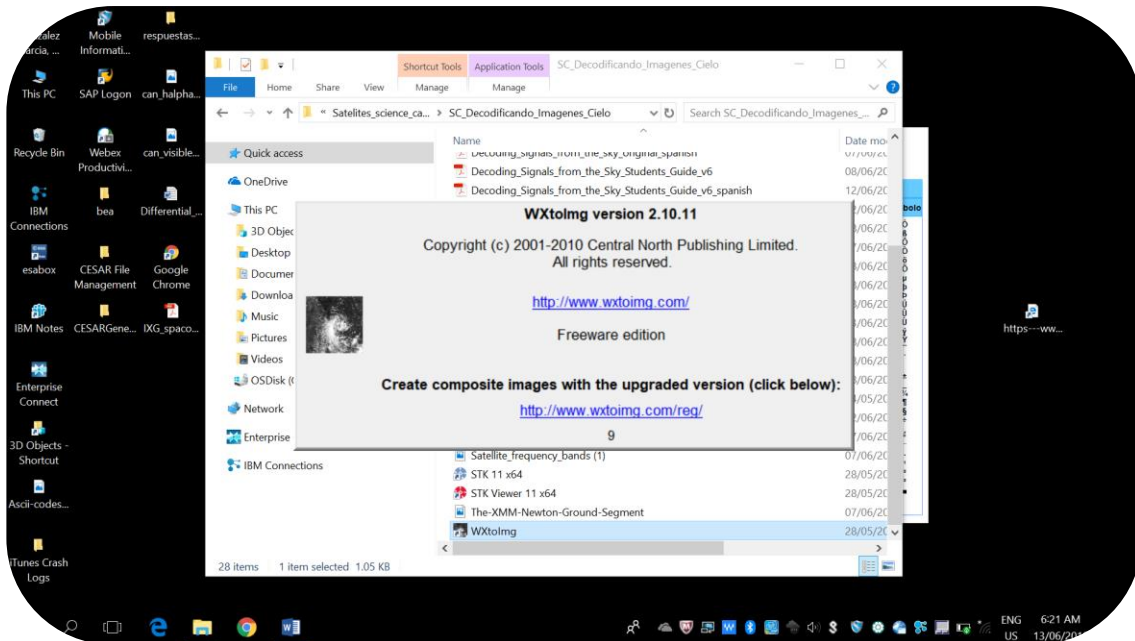


Figure 11: Step 1 to open the audio file of NOAA 18 on *Wxtolmage*. (Credits: CESAR)

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<sup>3</sup> <https://wxtoimgrestored.xyz/downloads/>

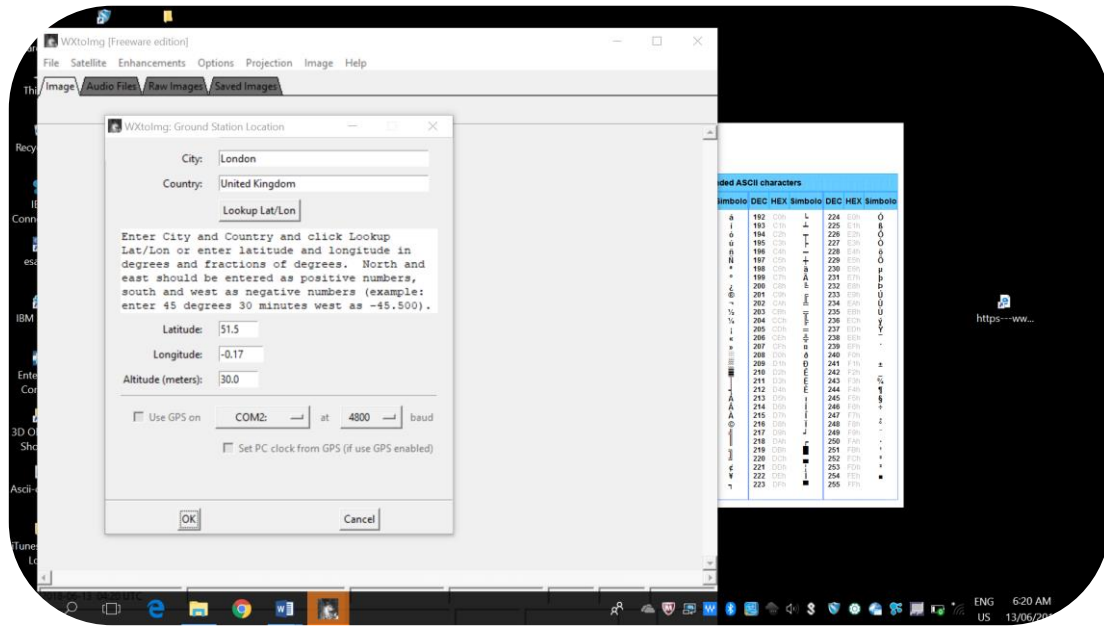


Figure 12: Step 2 to open the audio file of NOAA 18 on Wxtolmg. (Credits: CESAR)

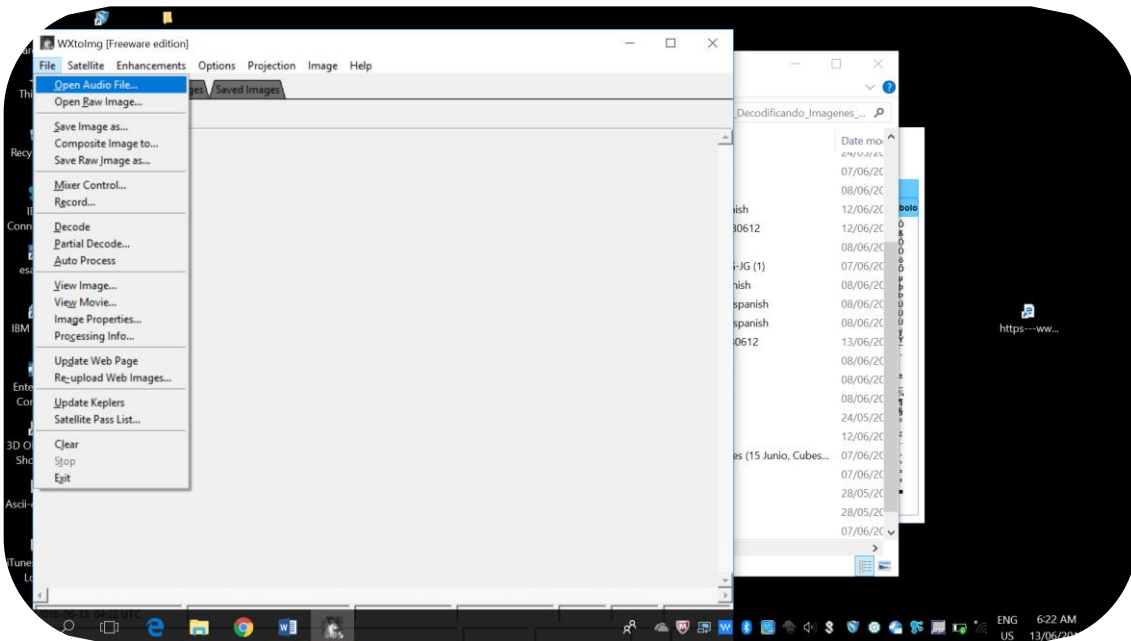


Figure 13: Step 3 to open the audio file of NOAA 18 on Wxtolmg. (Credits: CESAR)

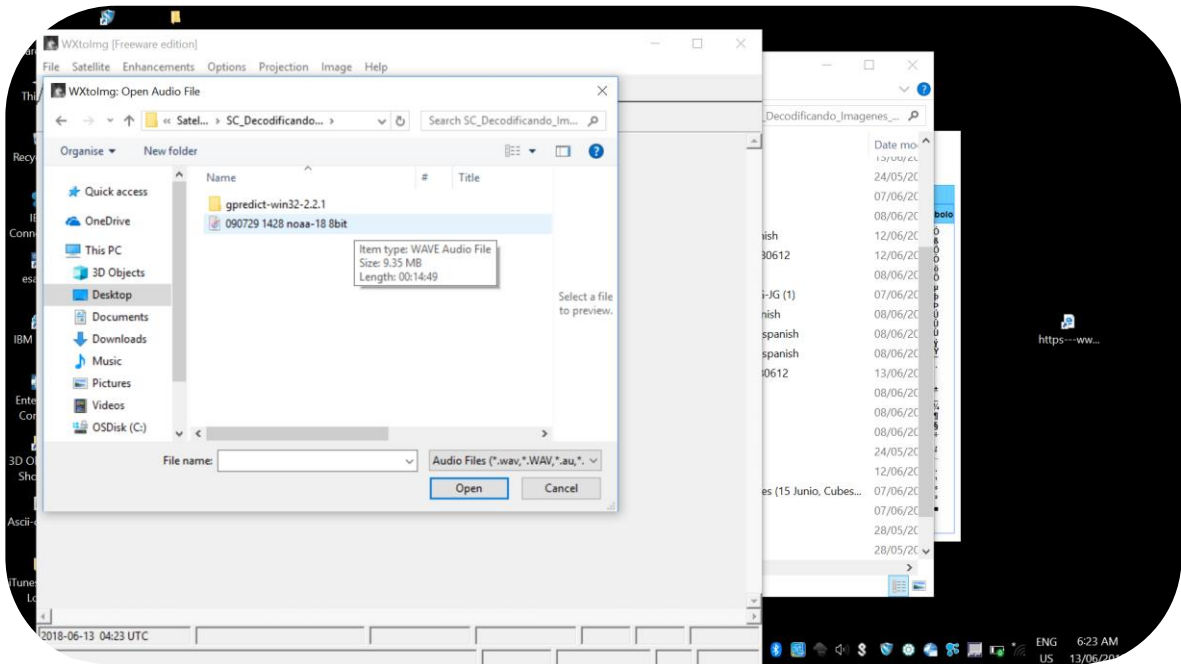


Figure 14: Step 4 to open the audio file of NOAA 18 on Wxtolmg. (Credits: CESAR)

Identify the geographical region covered by the satellite and estimate the size of the area covered.

After opening the audio file in this activity, an image like Figure 15 will appear on the screen. In order to observe the image properly, we may need to resize the image.

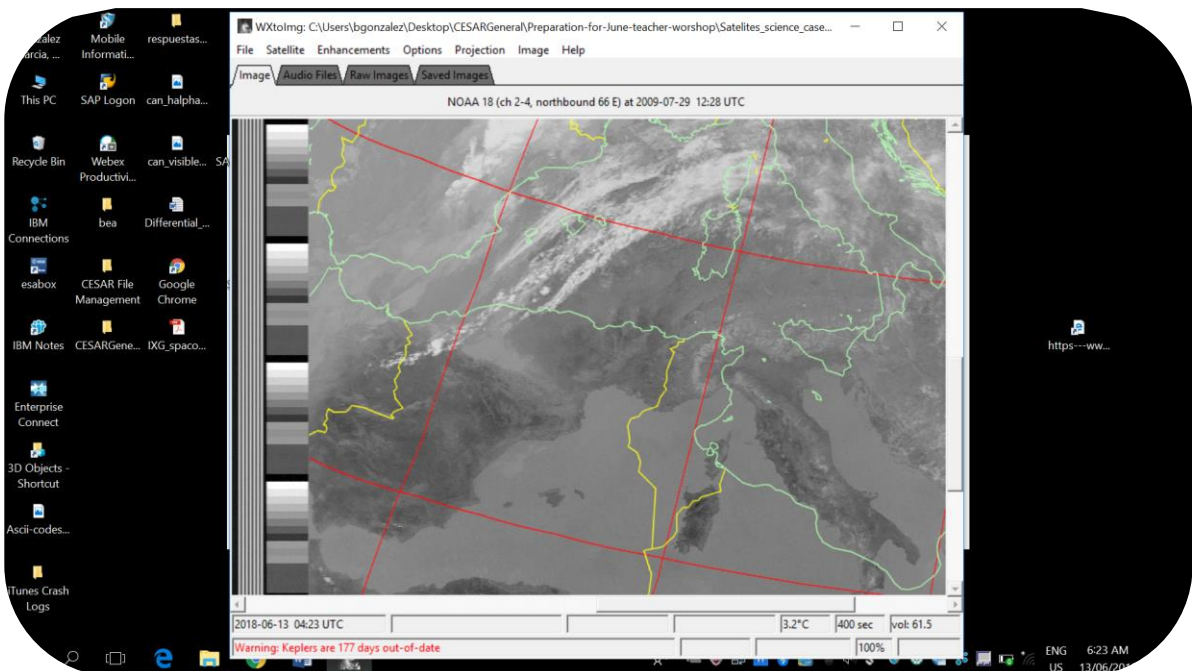


Figure 15: Step 1 to resize the image on Wxtolmg. (Credits: CESAR)

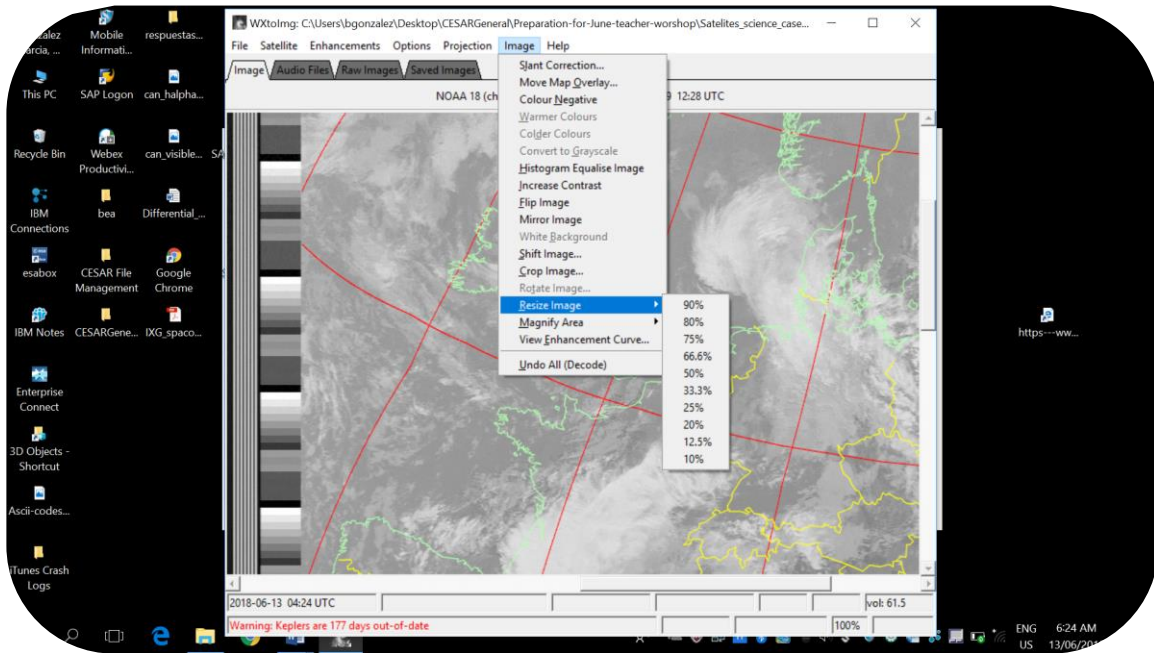


Figure 16: Step 2 to resize the image on WxtolImage. (Credits: CESAR)

The first step is to notice whether the map outline (the light green lines) **adjusts to the map** or not. By default, this is not the case. The way to adjust it is as shown in Figure 17.

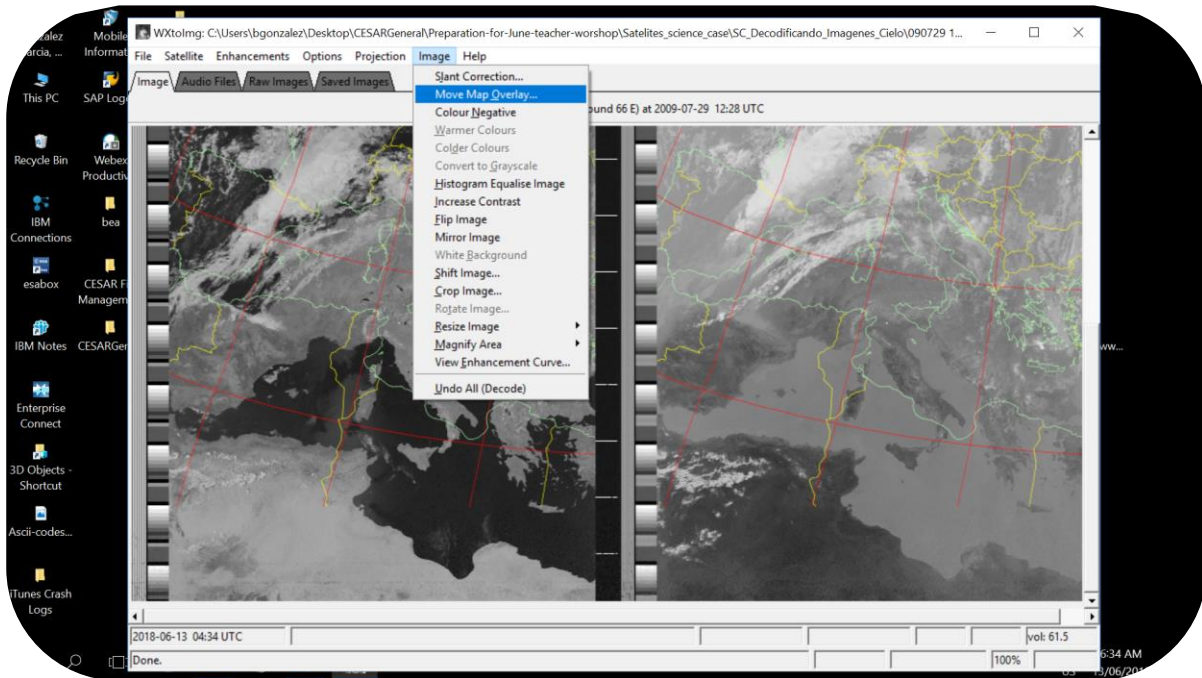


Figure 17: Step 3 to resize the image on WxtolImage. (Credits: CESAR)

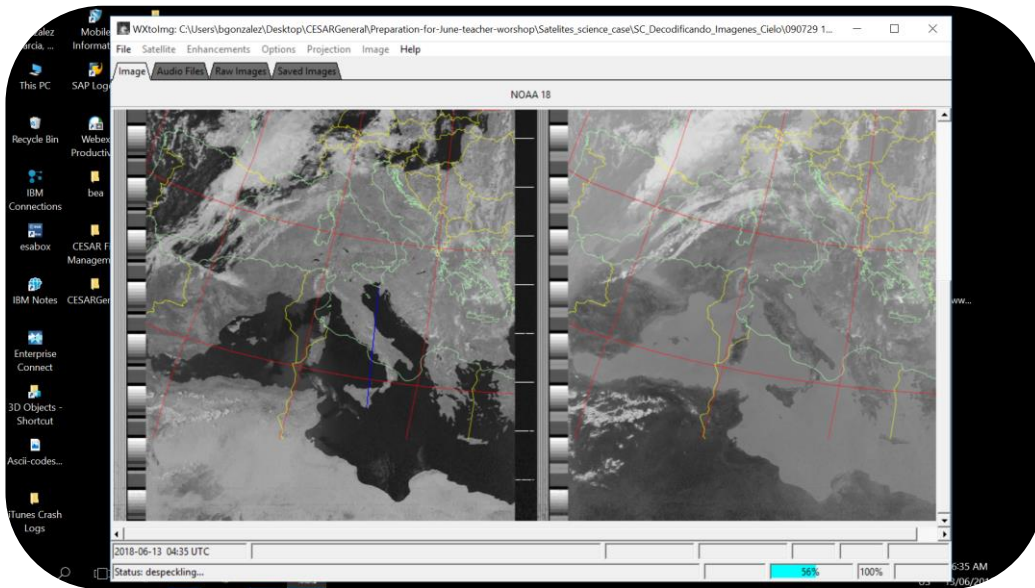


Figure 18: Step 4 to adjust the map outlines of the image of NOAA 18 on WxtolImage. (Credits: CESAR)

### Step 3: Colour the image

The use of false colours helps highlight the characteristics of the images according to the application. A list of some of the improvements in the visualisation (*Enhancements*) offered by WxtolImage software are applied in this part. Their detailed description can be found at the end of this science case. The option is *Enhancement*, as in Figure 19.

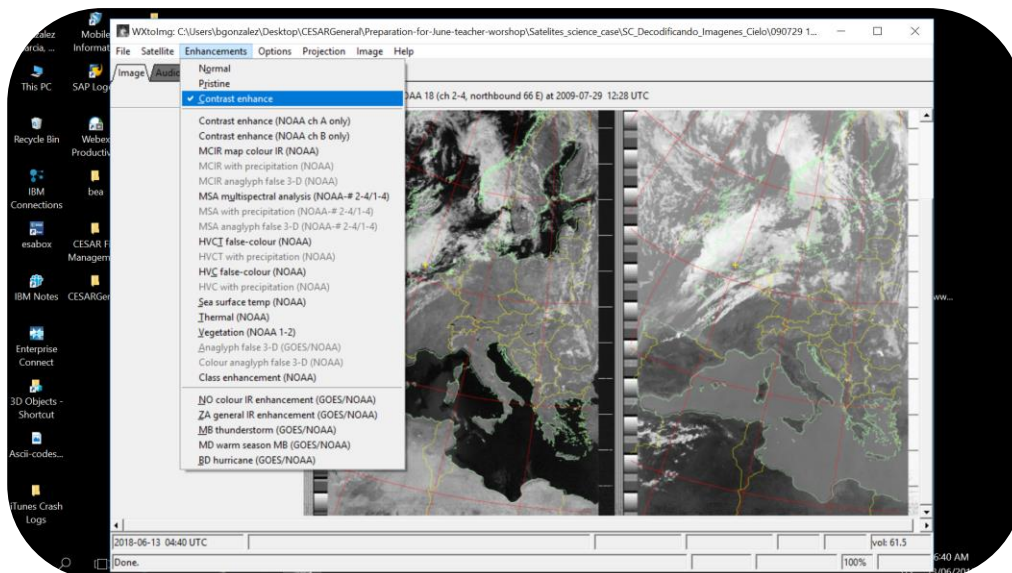


Figure 19: How to apply Enhancement on WxtolImage. (Credits: CESAR)

Note: Each time we apply a visualisation option we will lose the size selection of the image, so we need to resize it again.



Using different visualisations to analyse the content of your image, answer the following questions:

1. Study the temperature of the surface of the sea selecting the “Sea Surface Temperature” Enhancement (NOAA satellite). Do you get to any conclusion?

The colder areas are black. These are part of the land and the clouds. See Figure 20.

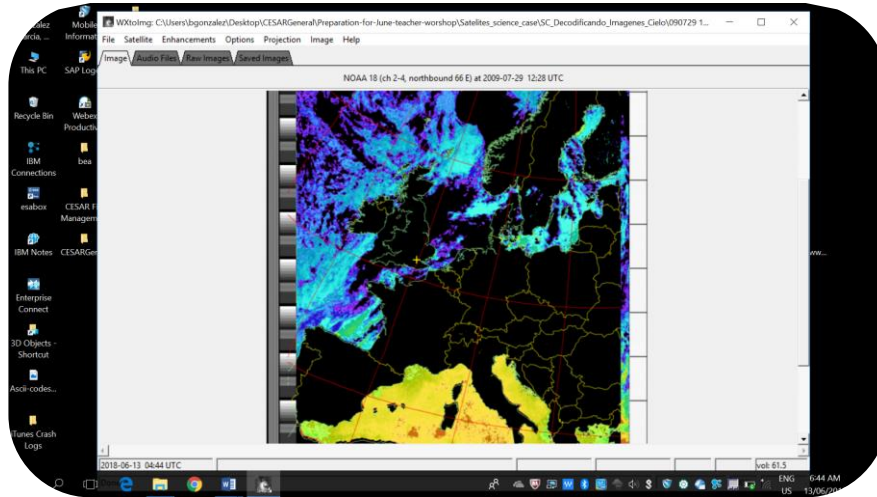


Figure 20: Sea Surface Temp Enhancement on WxtolImage. (Credits: CESAR)

2. Study the temperature of the map (NOAA satellite). Do you get to any conclusion? How does the region of the North of Africa look?

The hotter areas are the red ones, in the continent, mainly at the South of Spain, Italy and the North of Africa.

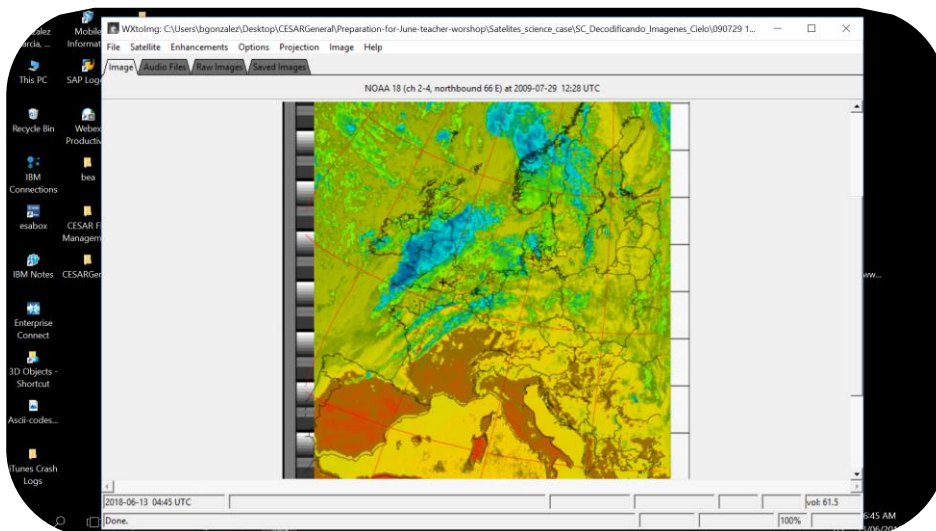


Figure 21: Enhancement Temp on WxtolImage. (Credits: CESAR)



3. If you wanted to see a more realistic image, which kind of Enhancement would you choose?

See Figure 22

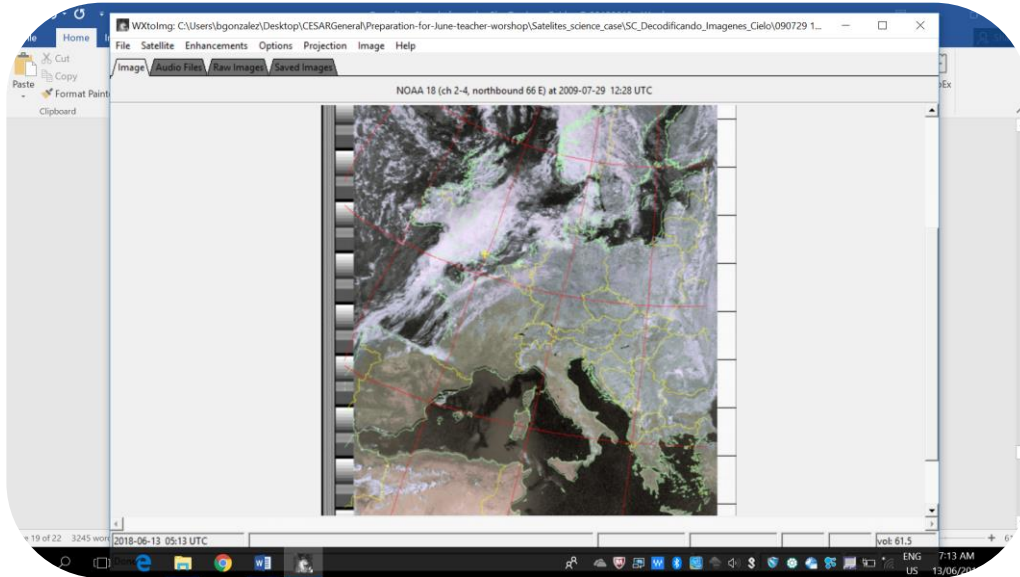


Figure 22: Enhancement Classic. (Credits: CESAR)

4. Look at the clouds in the image selecting “NO color IR Enhancement (NOAA)” Where are they?

The zones in which there is more cloud concentration appear green, such as the UK. See Figure 23.

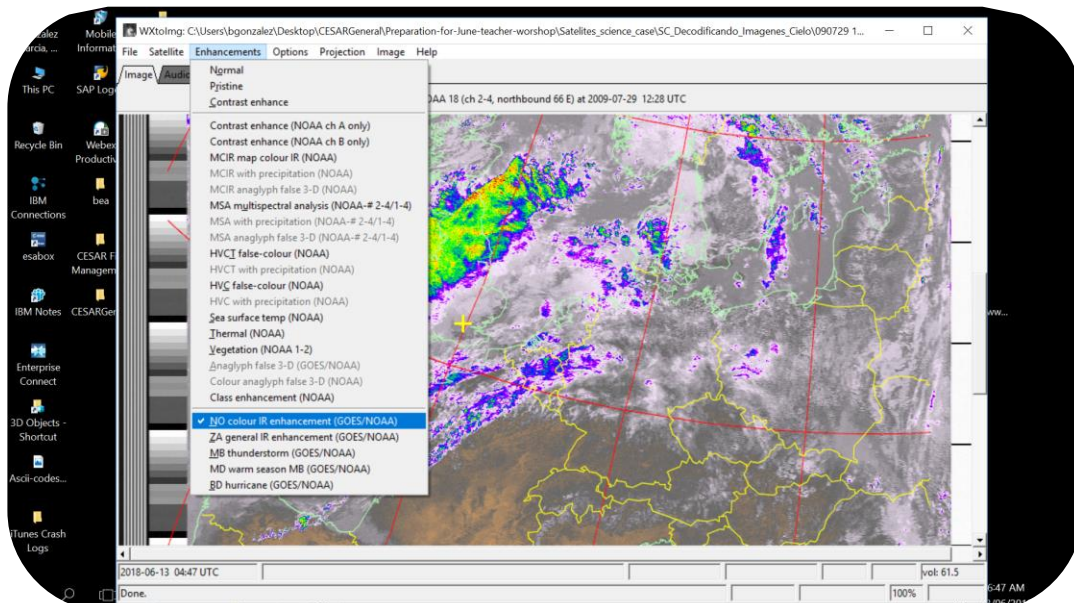


Figure 23: Enhancement NO color IR (NOAA). (Credits: CESAR)



5. To study the rains, select “MB thunderstorms”. What can you conclude on the weather from the image? Make your forecasts.

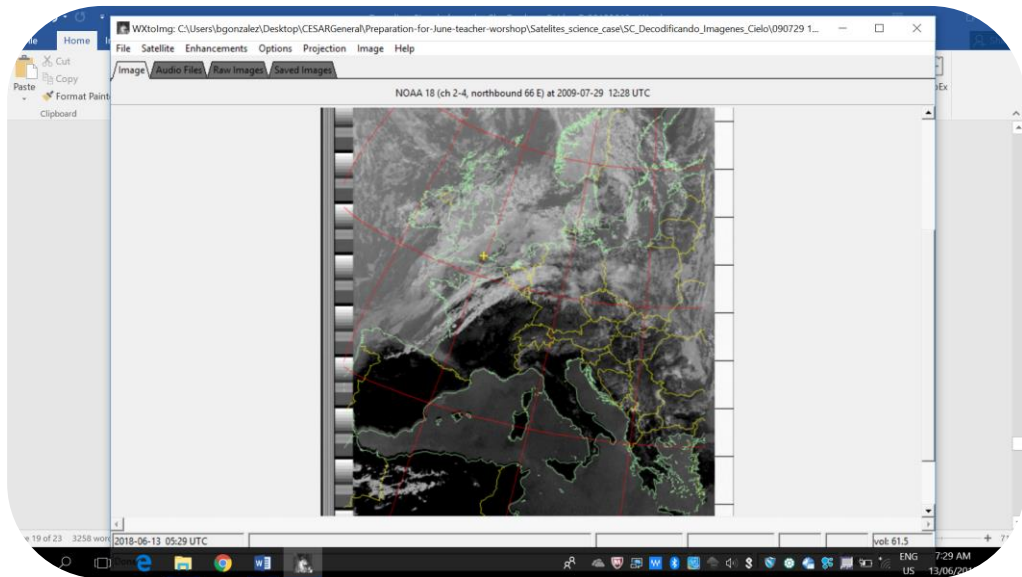


Figure 24: Enhancement MB thunderstorms. (Credits: CESAR)

### Explanation of the different images produced (*Enhancements*):

*Normal*: Produces a regular image.

*Pristine*: They are images with no added improvements, they are only normalised. They are the best representation of the original data.

*Contrast enhance*: Uses contrasts.

*Contrast enhance (NOAA ch A only)*: Contrasts in the image seen by channel A of the satellite NOAA.

*Contrast enhance (NOAA ch B only)*: Contrasts in the image seen by channel B of the satellite NOAA.

*Sea surface temp (NOAA)*: Creates an image of false colour based on the temperature of the surface of the sea taken by NOAA APT. These data are taken by 4 sensors that determine the temperature value. The regions of inside land appear as black, as well as the high clouds. The values of the temperatures can be very inaccurate if there are low clouds or small thin clouds or if the signal contains a lot of noise.

*Thermal (NOAA)*: Produces an image of false colour based on the measurements of temperatures of NOAA APT. It provides a good method to visualise the temperatures of the clouds.

*Class enhancement (NOAA)*: Employs an iterative optimisation method for the images after being processed.

*NO colour IR enhancement (GOES/NOAA)*: Increases the contrast, darkening the sea and interior regions and colouring the colder parts of the high clouds. This improvement is done by normalising the values of the temperature.

*MB thunderstorm (GOES/NOAA)*: Improves the visualisation of the cold high clouds. It is very useful to show the strongest rains and storms. The values of temperature are normalised.





## Links

- Wxtolmg <http://www.wxtoimg.com/pics/>, <http://www.wxtoimg.com/support/wxgui.pdf>

(\*) **modulate:** “vary a characteristic of a carrier wave according to a signal that transports information. The purpose of modulation is to superimpose signals on the carrier waves” (Wikipedia). Figure 20 shows a carrier wave that can be modulated in amplitude (AM) or in frequency (FM).

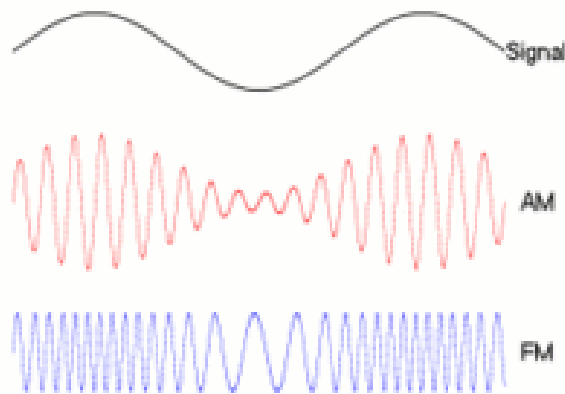


Figure 20: Explanation of the concept of modulation. (Credits: Wikipedia)