

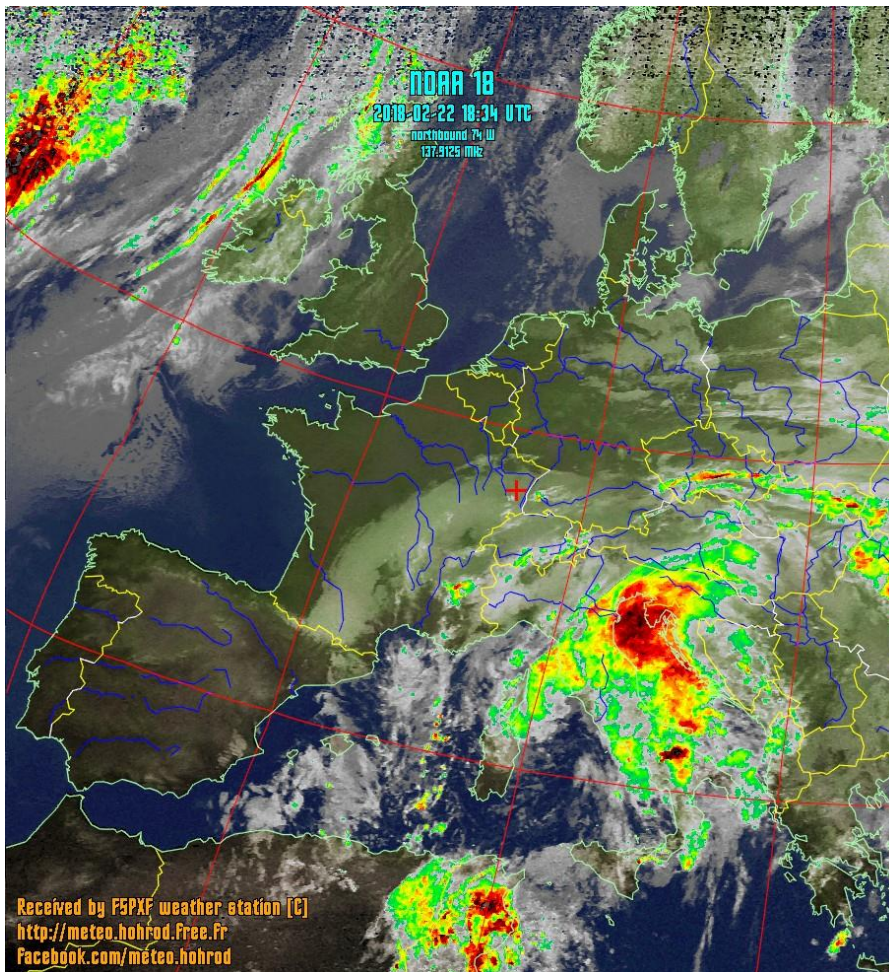


CESAR Science Case

Decoding Signals from the Sky

How do satellites communicate with the Earth?

Student 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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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 the components shown in figure 3:

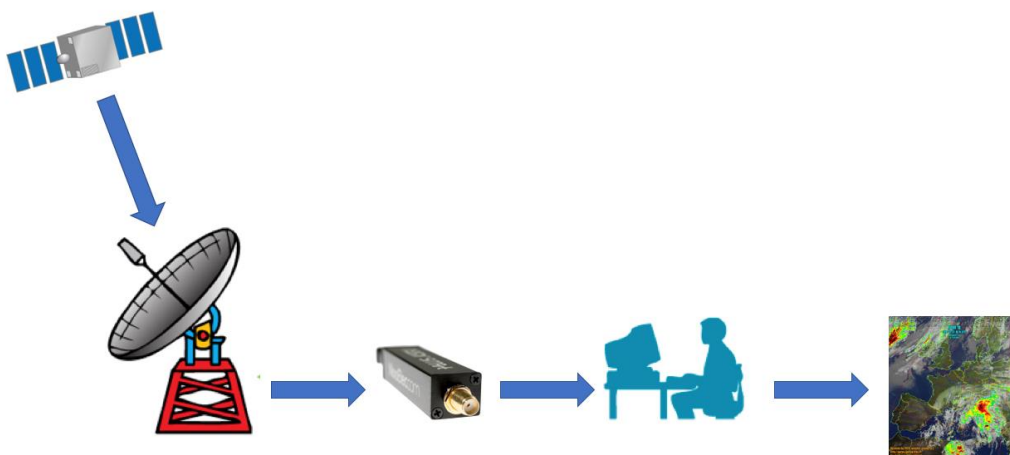


Figure 3 : Communications reception system. (Credits: ESA)



- **Satellite:** In charge of performing a mission and placed in an orbit for it. Among its components two important ones can be distinguished, with their sub-components:
 - **Service module or platform:**
 - *On board computer:* controls each piece of the satellite by software.
 - *Telemetry subsystem:* prepares the information of the platform and payload 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.
 - **Payload:** 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 (telecommands) or the executed measurements (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*.

Plan the transmission with a satellite:

Activity 1: Hypothesis

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

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?

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.

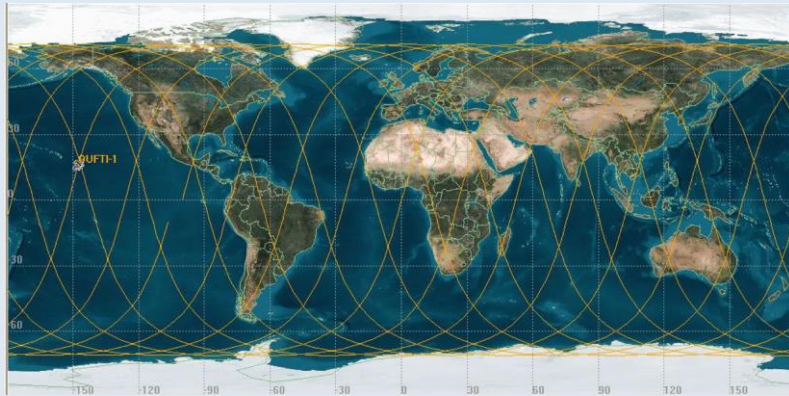


Figure 4 : Trace of a satellite like CubeSat OUFTI-1 on the map of the Earth. (Credits: ESA)

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 λ is the wavelength (in metres), ν is the frequency (in Hertz) and c is the speed of light (in m/s).



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

The CESAR initiative has two antennas that are 70 cm and 2 m long installed in ESAC. Look at Figure 5 and answer the following questions:

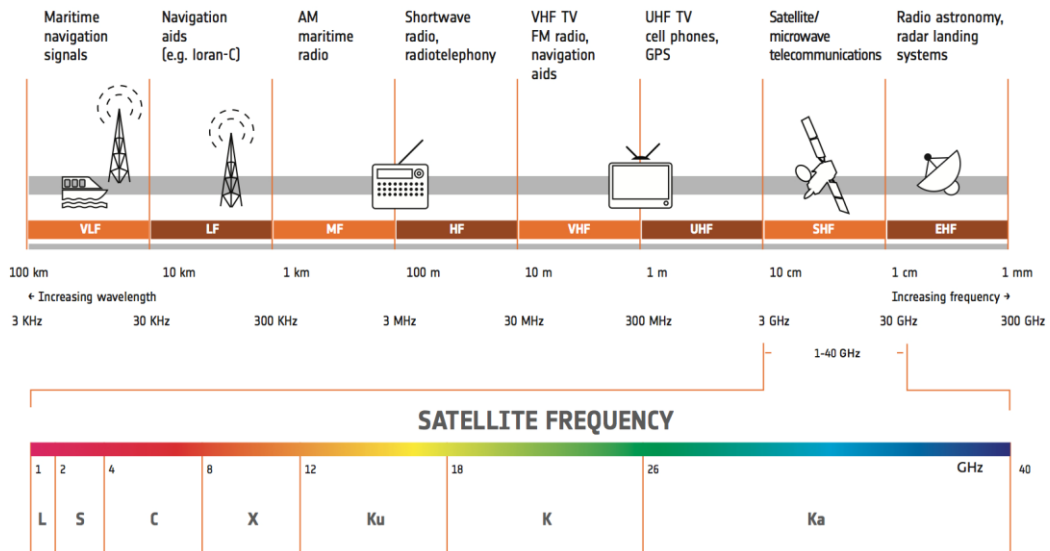


Figure 5 : Frequency bands employed by satellites of the ESA. (Credits: ESA)

1. What is the name given to the spectrum bands at which the antennas transmit/receive signal?

70 cm antenna
2 m antenna

2. Which everyday devices can interfere with the antennas?

70 cm antenna
2 m antenna



3. Considering that the signals travel through empty space, which frequencies would be transmitted/received by the antennas? *Hint: use the equation that relates the frequency to the wavelength and take the length of the antenna as the wavelength.*

70 cm antenna

2m antenna

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.

Activity 3: Plan contact with a satellite:

In order to plan contact with a satellite, you need to know when it is visible by your antenna. The satellite will be visible at a certain moment and at a certain place on Earth depending on the orbit it follows. Knowing when a satellite is visible is a very complex task and, for that purpose, we will use a programme called **gpredict**.

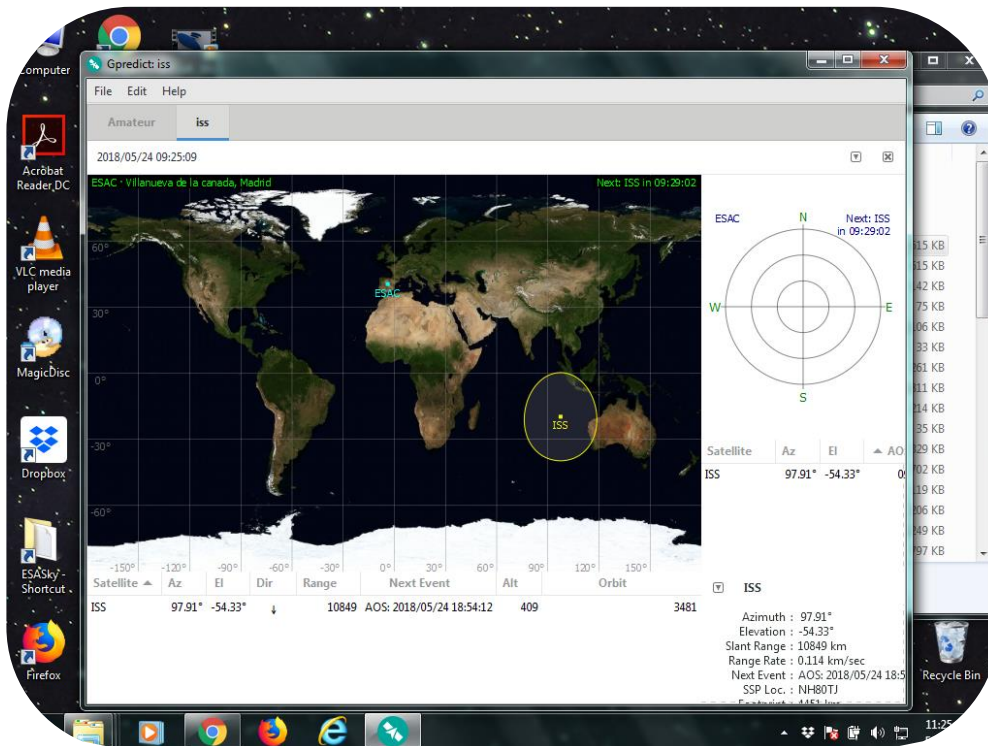


Figure 6 : Main window on gpredict. (Credits: CESAR)



Step 1: Getting to know *gpredict*

In this activity, you will use a software tool 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 afterwards to load this view.

Define the location of the station you will use to follow the 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			

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

Register the data in the tool following the steps (Figure 7):

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

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:

Edit → Preferences → Predict → Pass conditions →

Minimum elevation = 20 deg

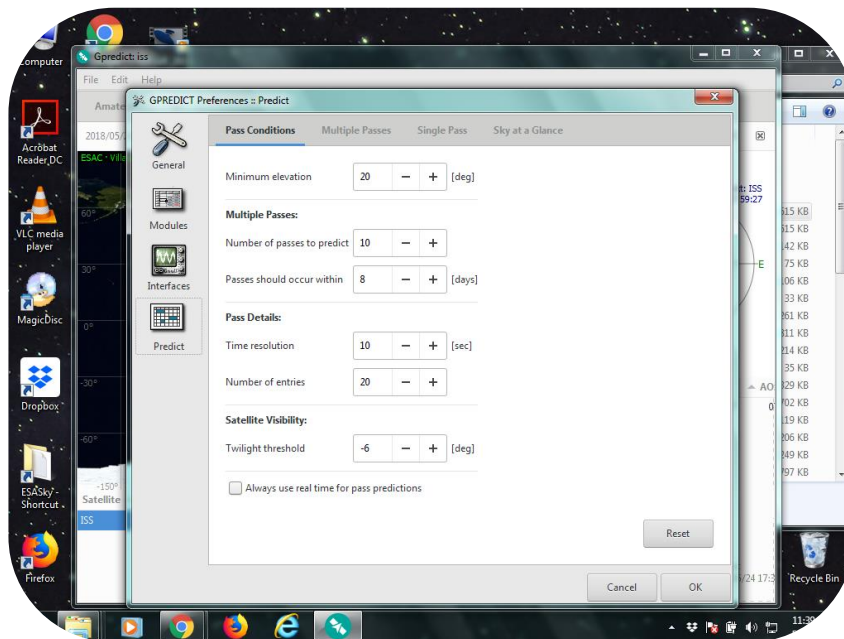


Figure 7 : Defining the limits of the antenna on gpredict. (Credits: CESAR)

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 the steps (Figures 8 and 9):

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

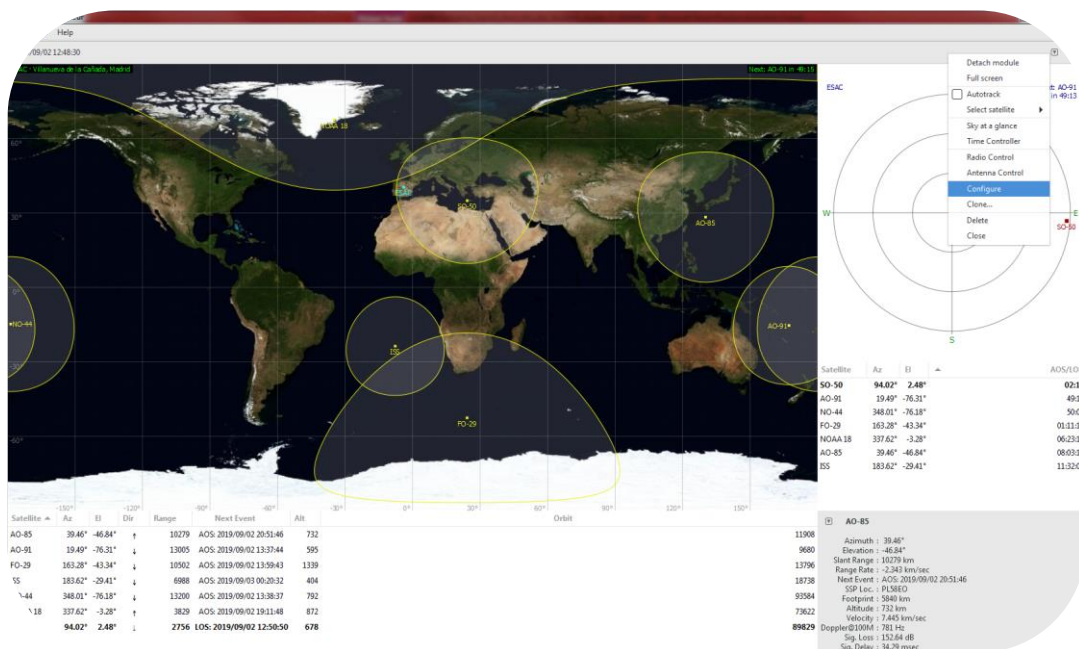


Figure 8 : How to configure the list of selected satellites on gpredict –step 1. (Credits: CESAR)

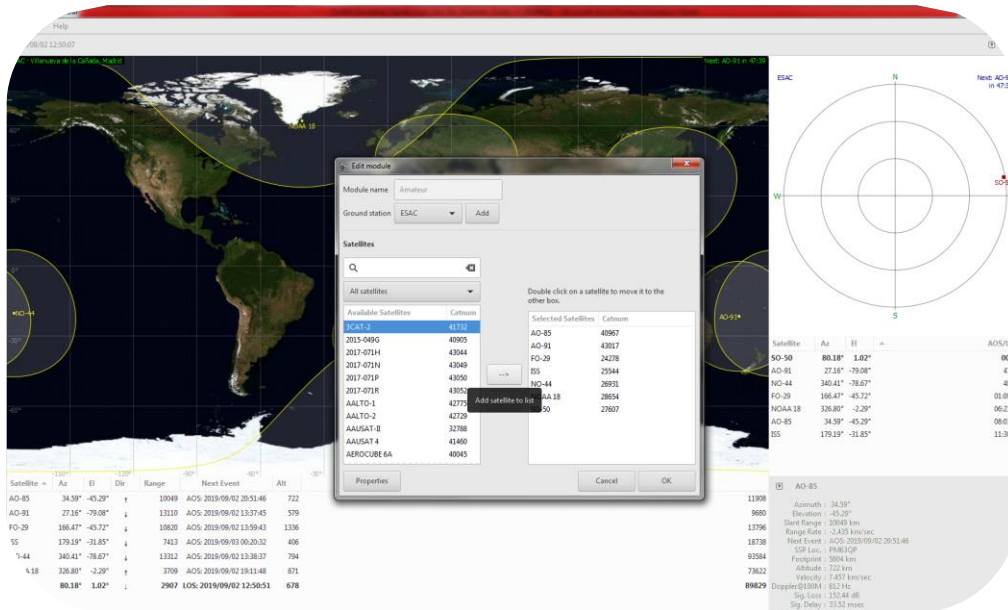


Figure 9 : How to configure the list of selected satellites on gpredict – step 2. (Credits: CESAR)

1. 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).

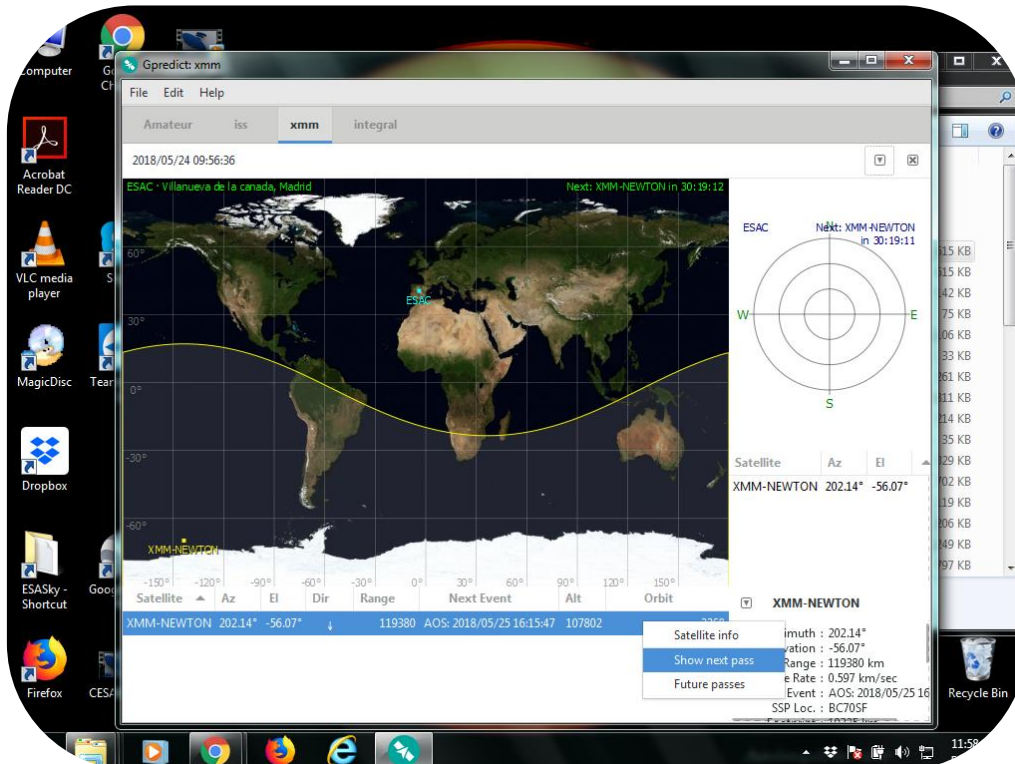


Figure 10 : Looking for information about the satellite and determining the next pass on gpredict. (Credits: CESAR)



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

Step 1: What is an audio file?

Select an audio file from your computer and listen to it. What information do you think it contains?

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

Step 2: What does an audio file look like?

What do you think is necessary to build an image?

Visualise your audio file with the software *Wxtolmage*.

Step 3: Getting to know the *Wxtolmage*¹ 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.

¹ <https://wxtoimgrestored.xyz/downloads/>



What region does the image show?

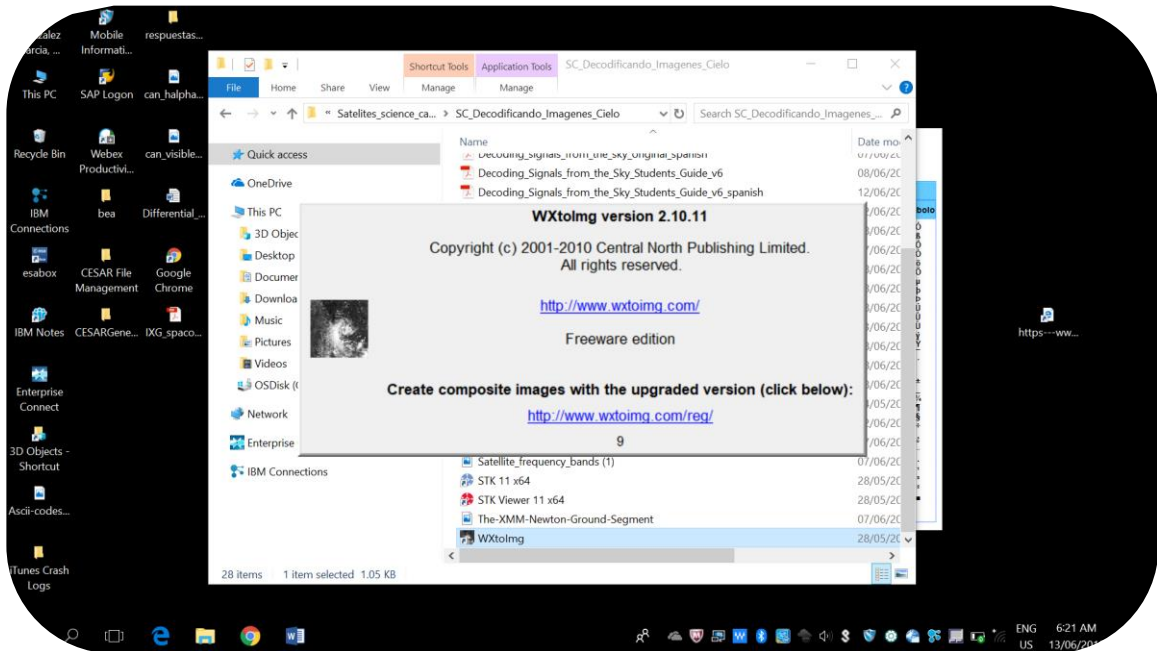
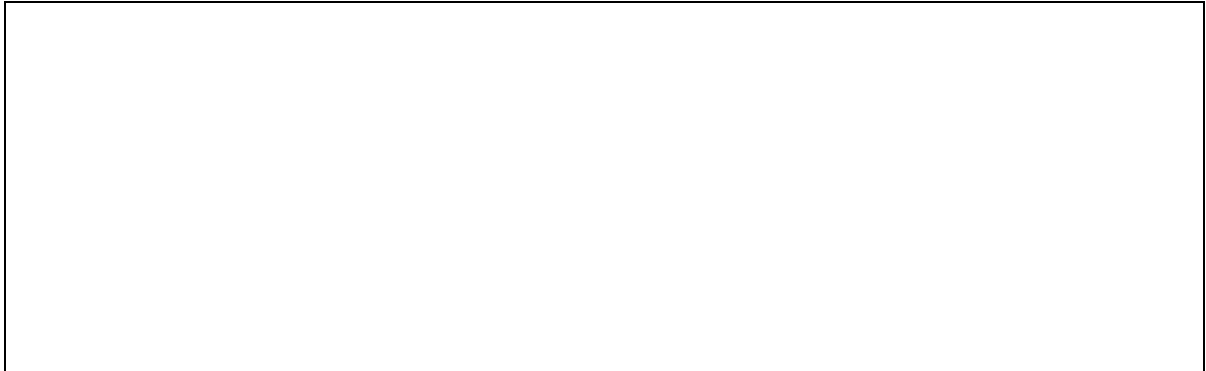


Figure 11 : Step 1 to open the audio file of NOAA 18 on WxtoImage. (Credits: CESAR)

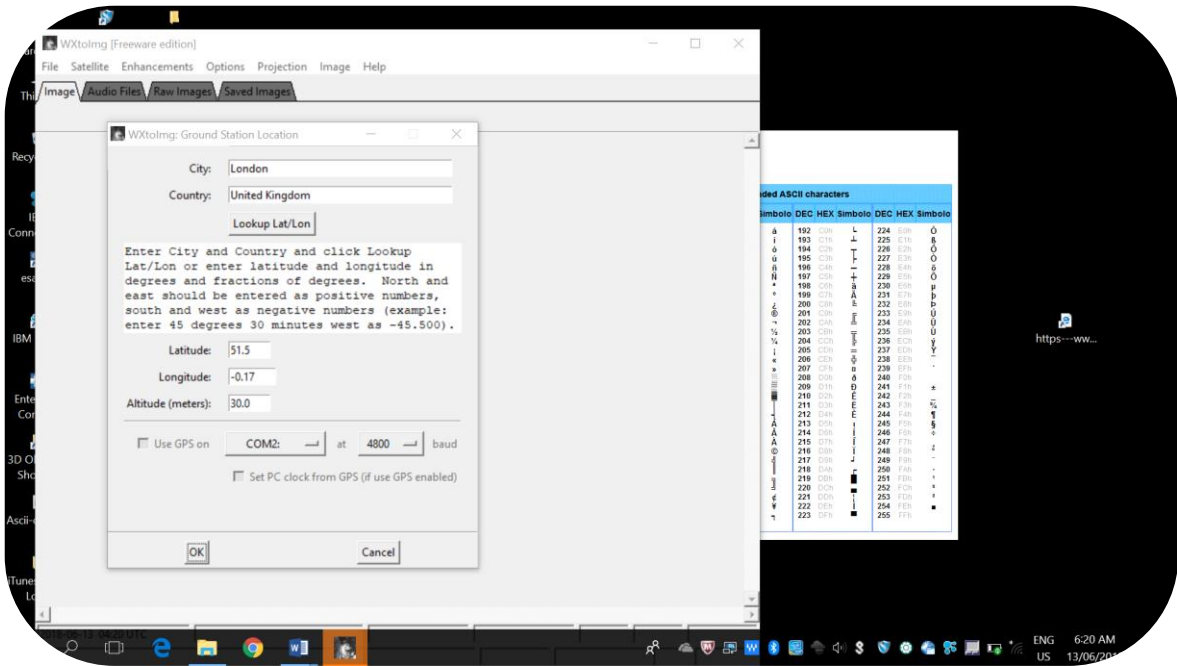


Figure 12 : Step 2 to open the audio file of NOAA 18 on WxtolImage. (Credits: CESAR)

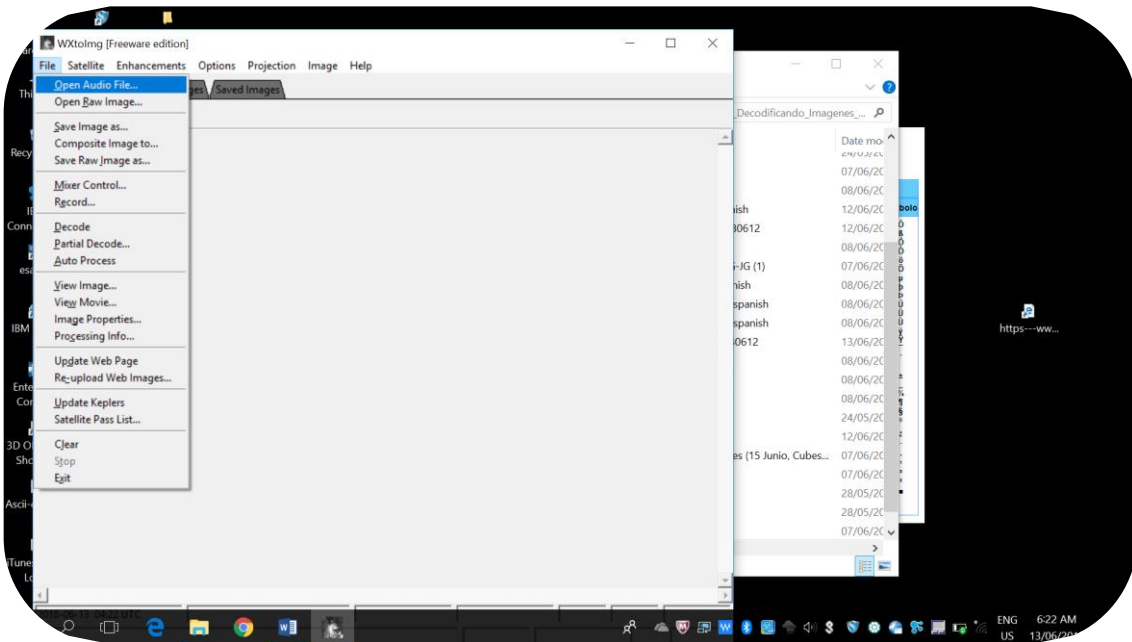


Figure 13 : Step 3 to open the audio file of NOAA 18 on WxtolImage. (Credits: CESAR)

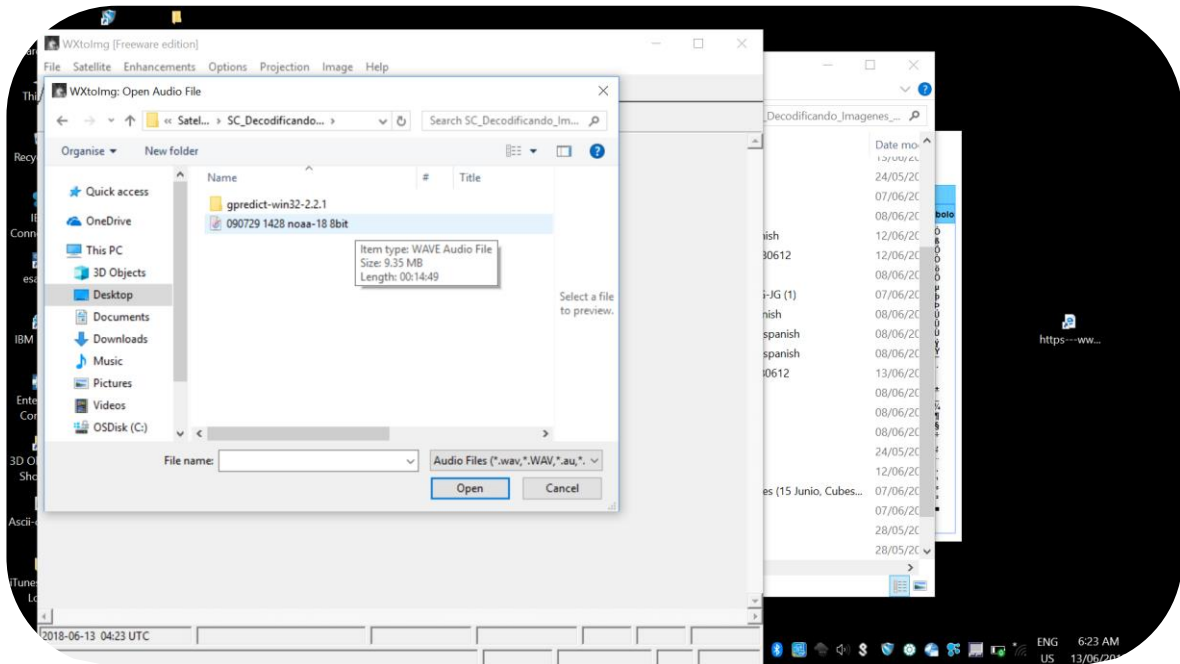


Figure 14 : Step 4 to open the audio file of NOAA 18 on WxtolImage. (Credits: CESAR)

Resize your image for a better view following the steps shown in Figures 15 and 16. You can do this multiple times.

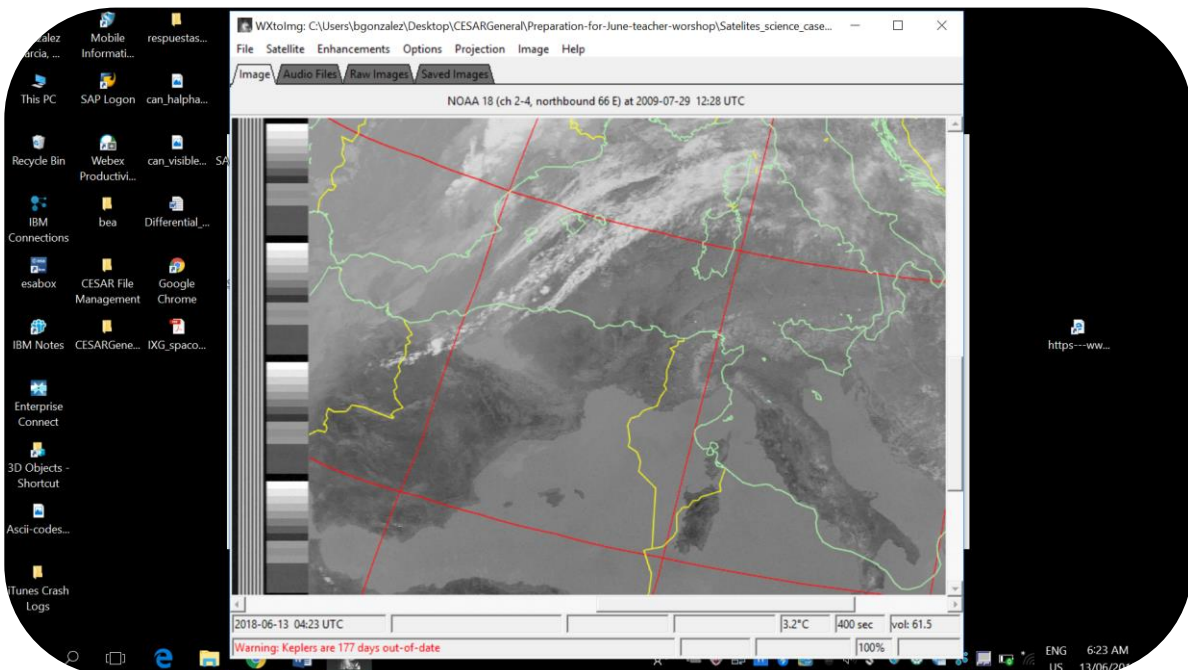


Figure 15 : Step 1 to resize the image on WxtolImage. (Credits: CESAR)

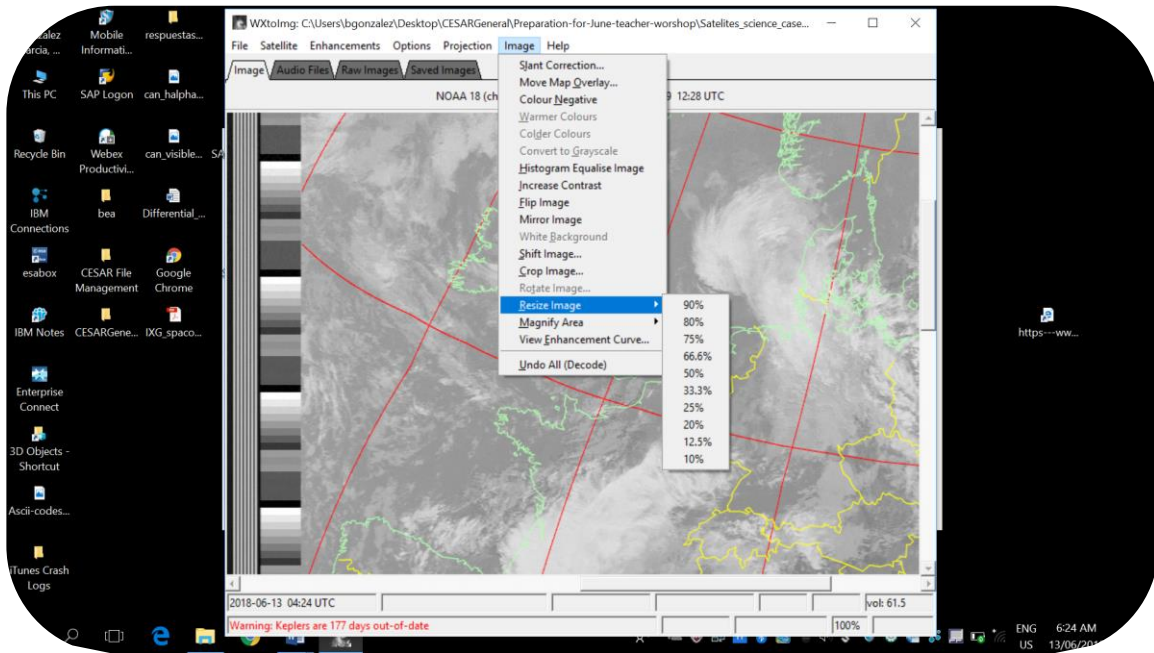


Figure 16 : Step 2 to resize the image on WxtolImage. (Credits: CESAR)

Do the map outlines fit the region in the image?

If this is not the case adjust the map outlines following the steps in Figures 17 and 18.

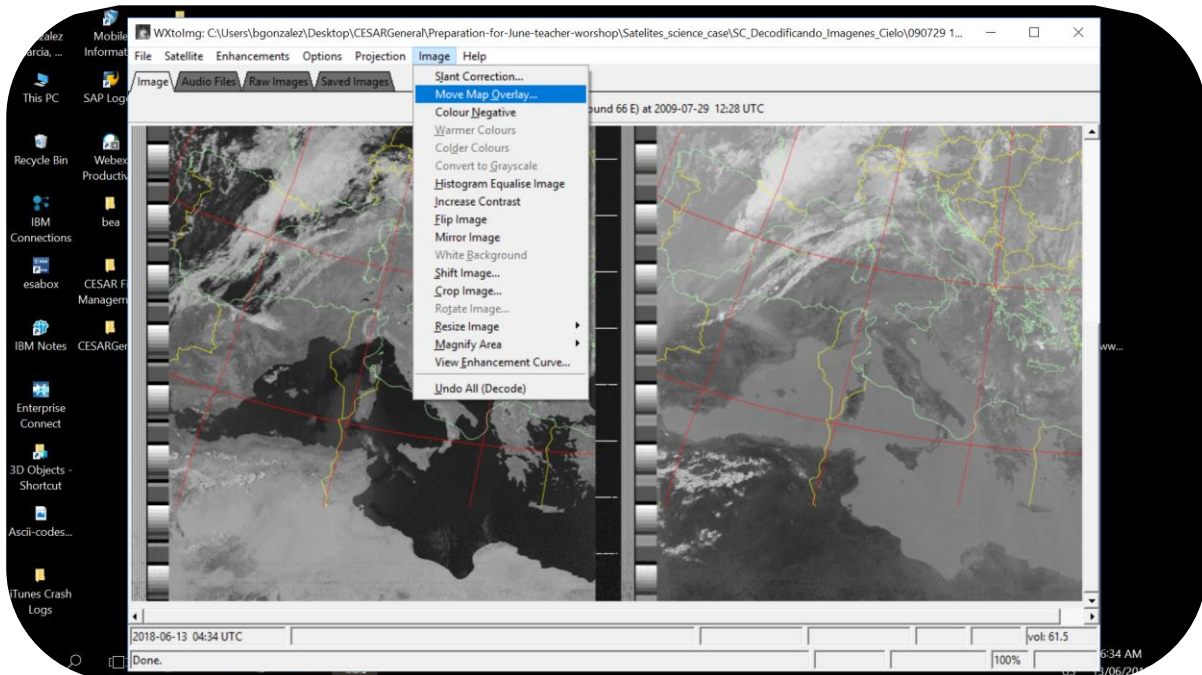


Figure 17 : Step 3 to resize the image on WxtolImage. (Credits: CESAR)

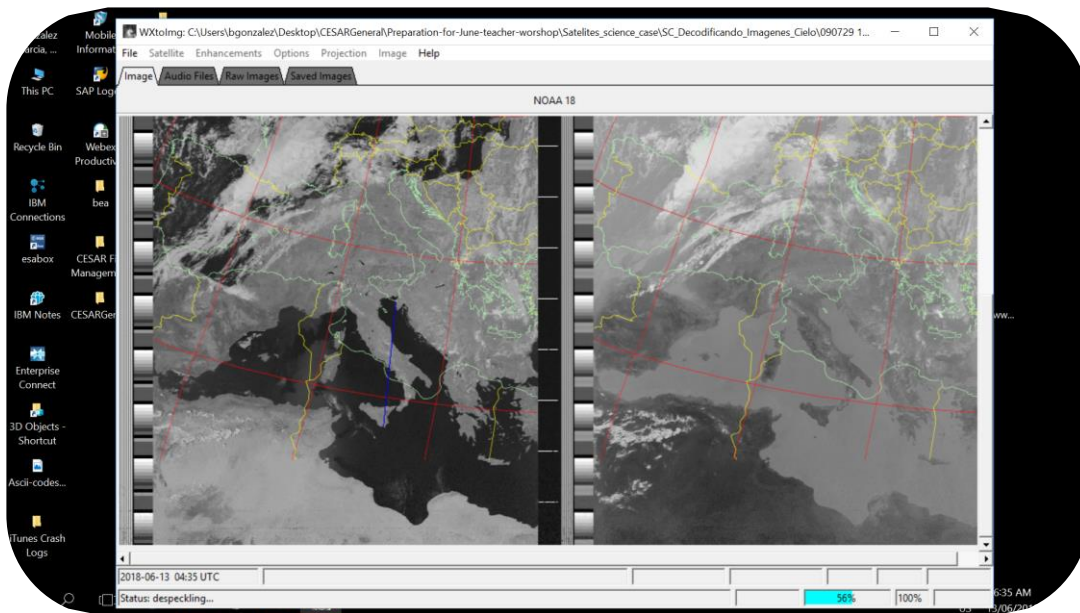


Figure 18 : Step 4 to adjust the map outlines of the image of NOAA 18 on Wxtolmg. (Credits: CESAR)

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 Wxtolmg 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.

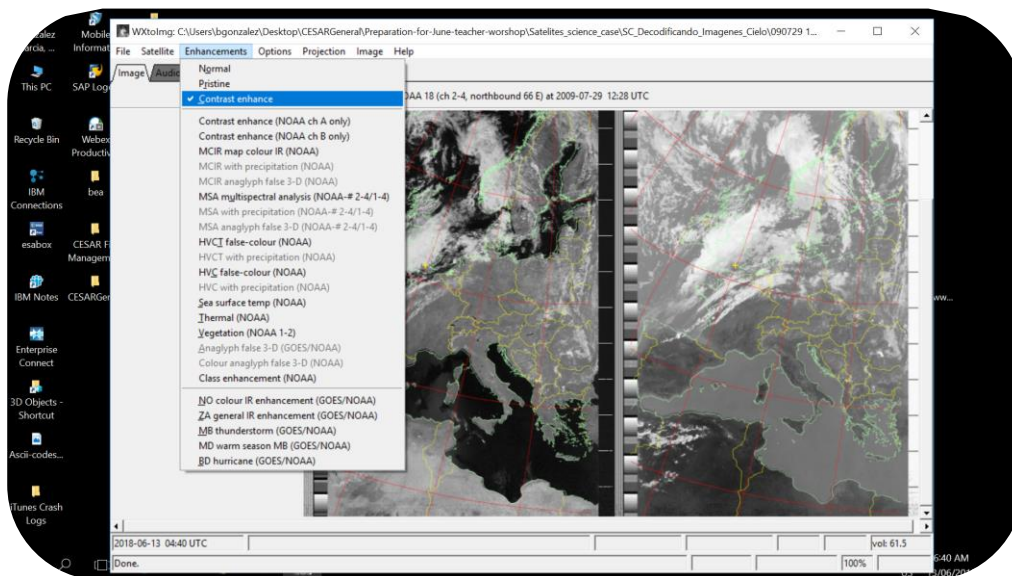


Figure 19: How to apply Enhancement on Wxtolmg. (Credits: CESAR)



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

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

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?

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

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

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

(*) **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).

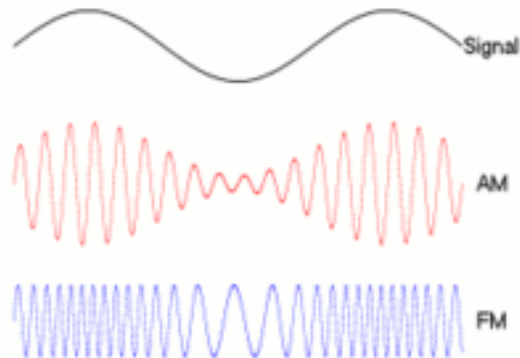


Figure 20 : Explanation of the concept of modulation. (Credits: Wikipedia)

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>