Heading: Altimetry (producing land and ice height maps from space)

Tags/crossover topics:

- Ocean
- Land
- Human Impacts
- Biodiversity

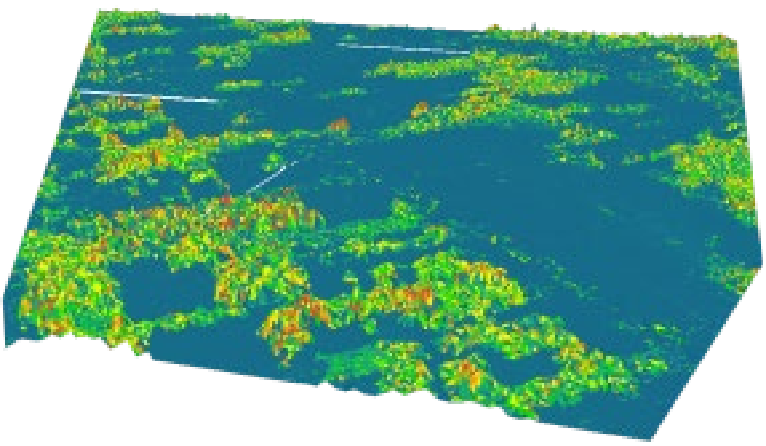
Introduction:

This activity will allow visitors to play the role of a satellite that is designed to measure and help produce a model of Earth surface features.

The surface of our planet is constantly changing. Landscapes erode, mountains grow slowly higher, ice levels drop and building emerge. Studying the structure of the Earth's surface, and producing maps of elevation across the planet are useful for monitoring everything from vegetation health and density to the effects of climate change on the ice sheets. And to get a full picture of how the surface of the Earth is changing, you need to do this from space.

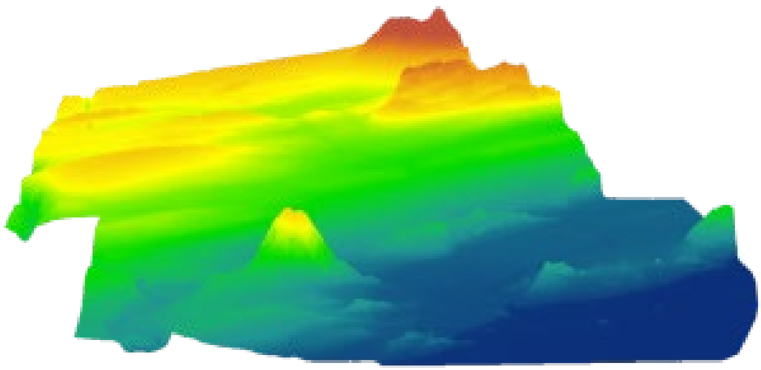
The science of creating maps that give the elevation of points across the surface of the planet is called DEM (Digital Elevation Modelling). Two main types of models can be produced:

DSM (Digital Surface Modelling) – includes all objects on the surface of the Earth including buildings, trees and other features. Produces a full, combined map of the topography of the Earth. This is particularly useful for monitoring vegetation growth in areas such as rainforests (including monitoring deforestation in remote areas) and urban planning.



A DSM model – the lighter and redder areas are showing a tree canopy.

DTM (Digital Terrain Modelling) or DEM (Digital Elevation Modelling) – gives a profile of the bare surface of the Earth, with all other features removed. It is used most widely to map terrain stability, hydrological features and in soil mapping.



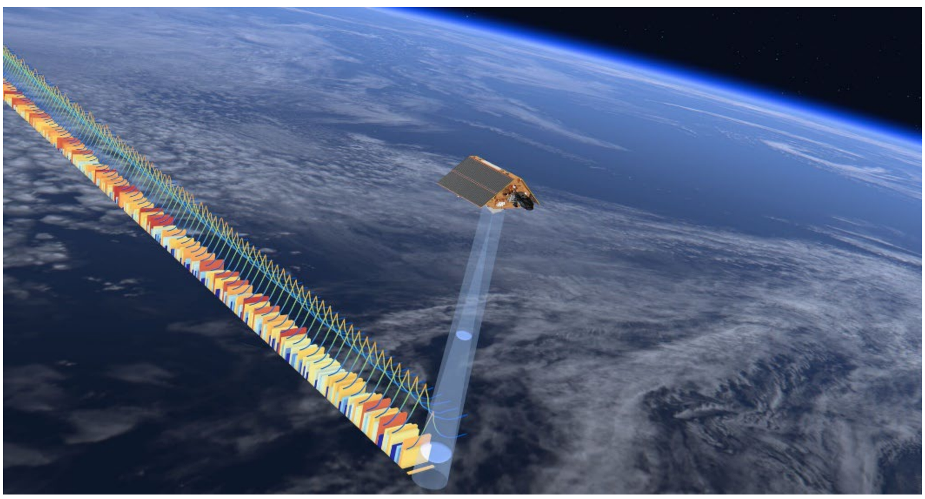
A digital elevation model showing 'bare earth'

Obtaining the data:

There are three main ways that satellites can obtain the data necessary to build these models:

Radar Altimetry

The word altimetry refers to measuring the altitude of features on the Earth. Just as with radar systems on Earth, this method involves timing how long it takes an emitted radar pulse to travel to the surface of the planet, reflect back and be picked up by a detector on the satellite. The longer it takes, the further the pulse has travelled and so this can be used to determine the distance from the satellite to the surface. ESA's Sentinel 6 satellite posses such a radar, which can be used with other techniques to provide accurate terrain models.

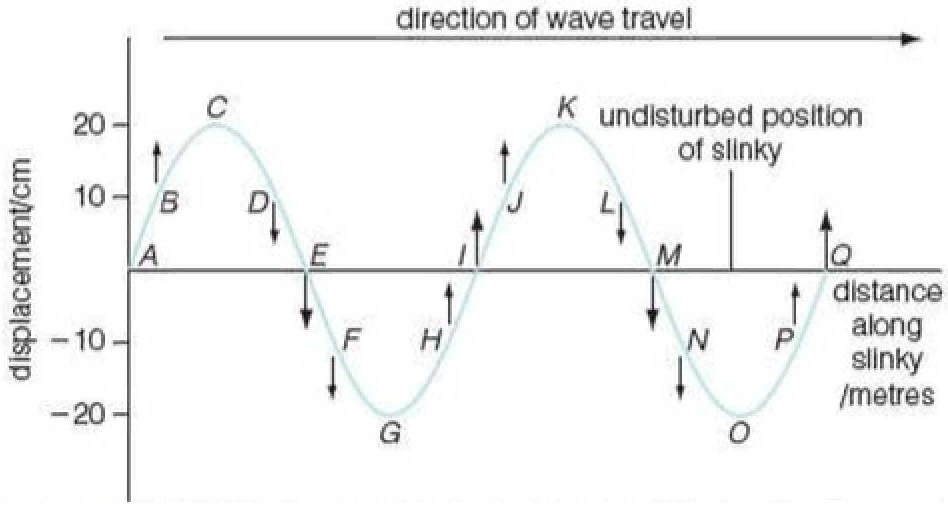


ESA's Sentinel 6 satellite

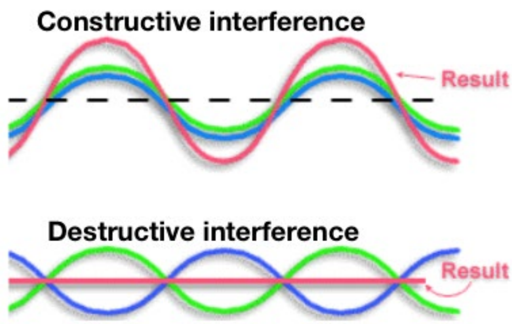
Satellite interferometry

To understand interferometry we need to understand the concept of phase when it comes to waves. Phase is a description of how far in a waves cycle, or oscillation the wave is. Two identical points of displacements (distance from the equilibrium, or rest position on the wave) will have the same phase, for example a peak and a peak. To points half a cycle apart will be in complete antiphase, for example a peak and a trough.

In the following diagram points C and K are both at a peak, therefor are in phase. Points C and G are a peak and a trough, half a cycle apart, and are therefore in antiphase.

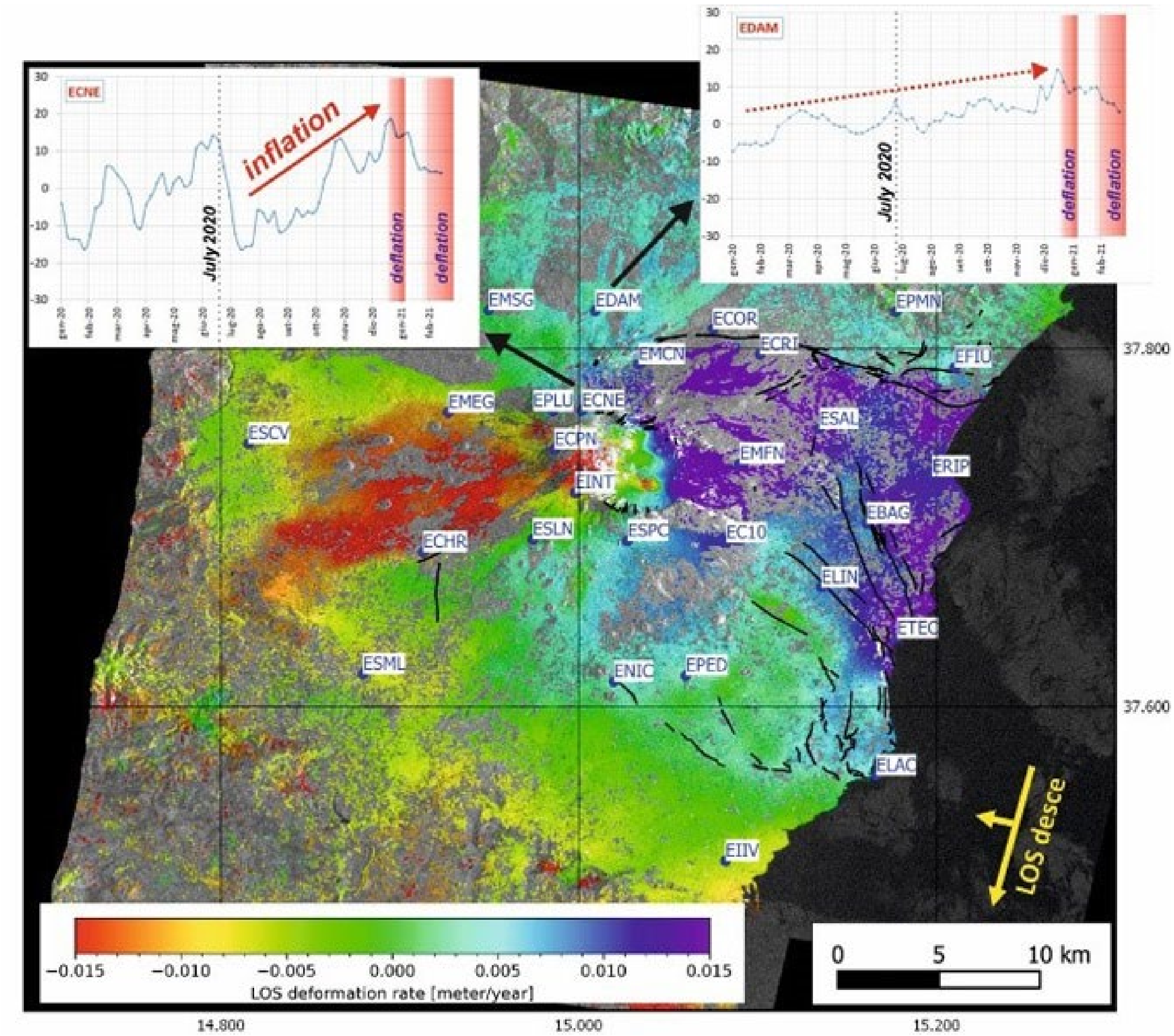


When two waves of the same wavelength meet, they will combine, or superpose, to add together the displacements of both waves. If they meet in phase, then you will get the maximum possible addition of displacements, causing what we call constructive interference. If the waves are in antiphase, a peak will meet a trough. This means that a maximum positive displacement is combined with a maximum negative displacement resulting in cancelling out, or destructive interference.



Interferometry is a method of detecting changes and deformities in the surface of an object. If you beam two microwave radar pulses at a surface, and they take exactly the same time to travel to the surface and return, then they will arrive in phase and can be constructively combined to form a perfect image. If there is a slight difference in the time taken to complete the journey, caused by changes in the surface caused by ripples, vibrations and other movements, then they will arrive at the detector out of phase causing interference. By looking at this interference analysts can deduce how much of a difference in distance each pulse travelled, and therefore how much of a change in surface height there was.

This is particularly useful in studying phenomena such as volcanic activity. ESA's Sentinel 1a and 1b carry a special type of interferometry setup called an advanced Interferomic Synthetic Aperture Radar (InSAR) that have allowed them to produce images showing the deformations caused before, during and after an eruption. Not only are the InSAR pulses able to penetrate beneath the cloud of an eruption from a safe distance, but these models are being used to monitor and help predict when eruptions might occur.

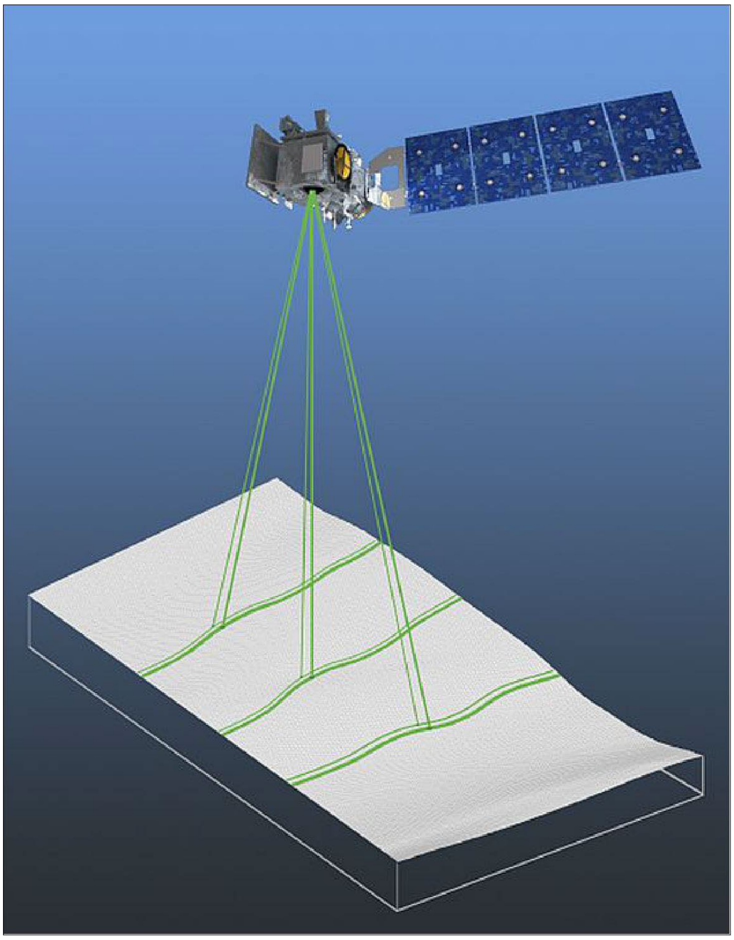


Sentinel INSAR data showing inflation and deflation prior to and after the 2021 eruption of Mount Etna

LIDAR (Light Detection and Ranging)

LIDAR is the optical equivalent of radar. Light radar techniques it uses a pulse of light (in this case a pulsed laser) to measure the distance to the surface by timing how long it takes the pulse to reach it, reflect and be detected by the satellite. And while it has its drawbacks (the light pulse cannot penetrate some materials including, depending on the light used, cloud) it produces terrain models with a much higher resolution than radar.

One example of this in use is NASA's ICEsat-2 (Ice, Cloud and land Elevation) which can get heights of forest canopies and continental ice sheets to a resolution of 3m!



NASA's ICESAT2

What makes LIDAR really useful is that different wavelengths of light will be reflected from different materials. EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) is a planned joint European/Japanese mission that will carry an ATLID (ATmospheric LIDar) capable of being reflected off clouds and aerosols to help characterise these within the atmosphere.

It is this final method that we are most closely modelling with this activity.

Kit list and any templates:

- Laser distance measurer capable of measuring to the nearest inch: This is the one I used
- Set of 1 inch wooden blocks: These are the ones we used
- Wood/super glue
- 2 x clamp stands and a wooden/metal pole (or design your own alternative way to hold the distance measurer above a table)
- Tape, card and scissors
- Printed satellite image of ICEsat-2 (please note the one used here was actually Sentinel-2 which does not have a LIDAR)
- LIDAR simulator land surface sheet
- Colouring pens/pencils
- Optional – cardboard box big enough to house the setup

Health and safety note: The distance measurer uses a laser – while these are low power care should be taken when using this set up and the best way to do this is with the box setup suggested in the differentiation ideas.

Method:

Setting up

Before the activity can take place, the ‘lidar simulator’ rig needs to be constructed. There are many possible ways to do this, the method detailed here was simply using the equipment available at the time.

1) Setting up the range finder

a) Use the user manual to set up the range finder so that it is taking readings in inches. For the range finder used here this is done as follows:

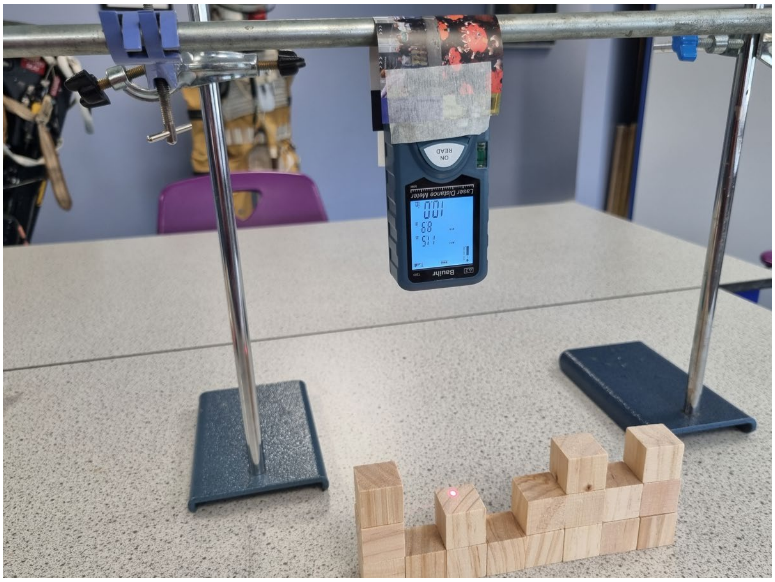
b) Press and hold the on button to turn on the range finder, then press the units button (bottom left) 4 times until the units displayed on the screen are inches.

2) Construct a loop so that you can hang the range finder from a pole
You may want to use alternative materials for this depending on whether you want this to be a permanent setup or a removable one. Since we wanted to be able to use the range finders for different versions of the activity we have used a temporary solution for this. Cut a piece of glossy thick paper or thin card to the same width as the range finder, and long enough to loop over a pole and cover all the buttons apart from the ON/READ button. This also helps reduce the chance of people accidentally changing the units setting. Use masking tape to form a loop at the bottom of the range finder, securing it on both sides. You can then slide a pole through the loop which you can then mount in anyway you chose – more on this in step 3.

3) Securing the pole and setting the height
Now you need a way of holding the pole horizontally above the table surface in a way that allows you to adjust the height of the pole. Here, two sets of stands and clamps were used to grasp the pole.

4) Set up the height above the table.
    - To keep this activity simple, you want the range finder to be reading in whole inches. Move the horizontal pole that the range finder is looped around towards the table until you get a reading of 10 inches. Make sure that you get the same reading at both ends of the pole, ensuring the pole is level.

5) Make your 'land'
    - Now, using the wooden 1 inch blocks, make your landscape profile. Stack the blocks on top of each other up to 5 high, and include some variation in height.



6) Double check
    - Do a quick test over each column of blocks to make sure that you are still getting a reading to a whole number of inches. If there is any variation, make a note of this and either increase the height (by adding

a small piece of paper between two of the block, or reduce the height by choosing to sand one down.

- Once this is complete you can glue the blocks together to form one complete section of 'landmass'.

Activity

This activity is designed to be done in pairs, with one person playing the role of satellite, and one of imager.

The satellite will move the range finder above the landscape one block at a time and call out the reading.

The imager will colour in this many blocks on the sheet. The remaining uncoloured blocks are giving an altitude for that column, or 'pixel'.

This process is then repeated until the entire landmass has been scanned, and the actual land profile can be compared to the one produced by the imager.

Differentiation - how can this be adapted for different audiences:

Making it more challenging (and safer!)

- You can make this activity more challenging by encasing it in a box, so only the horizontal pole and the ON/READ button are visible (perhaps with a door on the front that you can then open at the end to see how close you have come to the real result). Instead of measuring one column at a time, instead visitors must slowly scan across the surface, calling out when a change is observed.
- You can also make it more challenging by asking people to draw the profile of the land without using the colour in grid – how close do they come? To they realise that the numbers being given are the distance TO the landmass from space, rather than the height of the land mass

Upscaling the activity

- You can do the activity on a bigger scale (perhaps as part of a show or larger demo) by scaling everything up. The range finder can measure in feet, and even metres. You could hand it to a member of the audience and have larger blocks or a pre-formed landmass profile and get them to repeat the above steps holding it above and shouting the numbers to someone facing away from the stage who then has to reproduce the landmass profile.

Learning outcomes or discussion prompts:

Satellites use variations of echos to create accurate models of everything from the land, buildings, forest canopies, ice sheets and even clouds and aerosols.

As our technology improves we are constantly increasing the resolution (the smallest individual measurement we can take with an instrument) and therefor the accuracy of our data.

By linking in terrain data with other Earth Observation data such as sea surface temperature, we can begin to make connections between different areas of observation. Do changes in temperature create changes in ice sheet thickness, and therefore sea level? DO different aerosols in the atmosphere have an effect on vegetation health and therefore canopy height? And does the presence of lots of human made structures alter the base line terrain, water table and landscape?

Links for further info:

ESA information on LIDAR systems:
https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Space_Optoelectronics/LIDAR_Systems

How Sentinel monitored Mount Etnas eruptions: https://sentinel.esa.int/web/success-stories/-/copernicus-sentinels-monitor-etna-s-various-eruptions

Sentinel 1 SAR in depth information: https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-1-sar/product-overview/interferometry

Information on satellites using LIDAR: https://www.sps-aviation.com/experts-speak/?id=527&h=LiDAR-Satellites