Laser Quest 2 – above the waves
Seeing evidence for plate tectonics beneath the oceans - using satellites

This Earthlearningidea is an attempt to simulate the data collection method that enables satellites to map the ocean floor by measuring the height of the ocean surface. As such it should be undertaken alongside Earthlearningidea 'Laser Quest 1 – beneath the waves'

How high is the sky?
The ocean surface is not perfectly flat! While the ocean may appear to be level on a small scale, its shape is the result of a complex combination of the Earth's gravity field, its rotation, tides, ocean currents, atmospheric conditions and other factors that can each be individually identified and isolated. When the effect of the gravitational field is viewed alone, the ocean surface is seen to be undulating, with subtle bulges and dips reflecting the size, shape and density of the ocean floor features below. Underwater mountains, ridges, and trenches all exert different gravitational forces (anomalies) that pull on the water column above and around them. For example:

- underwater mountains (seamounts) have more mass and exert a strong gravitational pull. This draws more water around the seamount which piles up, causing the ocean surface to "bulge" upwards and outwards slightly**.** (Fig.1). An ocean ridge, like the Mid-Atlantic Ridge, causes the sea surface to rise by about 1 to 2 metres above the average sea level.

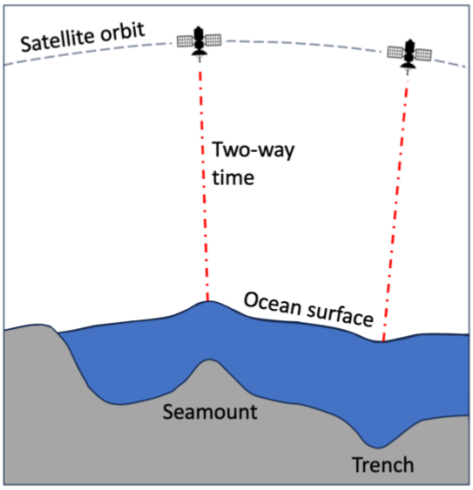

Fig 1: The satellite measures distance from its orbit height to the sea surface by timing the two-way travel time of radar pulses emitted by the satellite. The results are beamed down to a ground station. The positive gravity anomaly from a seamount creates a related bump on the ocean surface which is about 10,000 times smaller than the seamount. A seamount 1 km high produces a surface bump of about 10 cm. (*Pete Loader*)

- ocean trenches or deep valleys exert a weak gravitational pull causing the ocean surface to dip slightly. A deep ocean trench, such as the Mariana Trench, might cause a depression in the sea surface of around 1 metre or more.

These variations are usually very small (in the order of centimetres to a few metres), but when measured accurately using a satellite altimeter, they can reveal significant details about the shape of the ocean floor.

A satellite altimeter is a radar system that measures the distance from a low orbit satellite to the ocean surface. This is done by emitting radar pulses toward the ocean and measuring the time it takes for the pulse to travel to the surface and back to the satellite as it tracks across the ocean.

The simulation

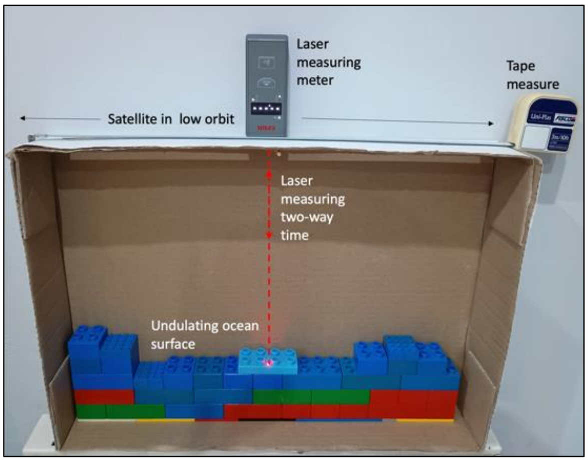

Fig 2: A laser distance meter measuring tool recording the depth from a satellite to a simulated undulating ocean surface– with box side removed to show the principle. (*Pete Loader*)

- Take a cardboard box or lid and cut a 1 cm wide slit along the top to allow the beam from the laser beam to reflect back from the 'ocean surface' to the meter. (Fig 2).
- Mark 1 cm intervals along the slit to assist with a systematic data collection survey.
- Using Lego™ bricks (or equivalent), create an 'ocean surface' showing slight variations which reflect the topography of the ocean floor produced in *Laser Quest 1* with which it should be compared. (Fig 3).
- Explain the two-way measuring principle of the laser measuring meter. Move the meter across the top surface of the box (representing the height of a low orbiting satellite) along the slit and vertically record data of the depth to the 'ocean surface' every centimetre. This will represent one survey track of a satellite across the ocean.
- Prepare a spreadsheet (Excel or similar) to convert the raw data (in cm) into appropriate height variations of the satellite above the ocean. Use the graphing facilities to draw the anomaly profile (or draw on graph paper by hand).
- Ask students to discuss the ocean floor features they might identify from the anomalies in terms of plate tectonics.

Data resolution
The ocean floor detail (resolution) shown by the satellite altimetry method is about equal to the depth of the water column above any ocean floor feature. In 4 km of water the resolution is about 4 km - so any feature less than 4 km is not likely to be seen clearly - but it is better where the water depth is shallower (ocean ridges or continental shelf). This means that details of the ocean floor landscape are smoothed out. (Fig. 2 and Fig. 3).

In contrast, the measurements from echo sounding surveys cover a much smaller area, with a resolution of 100 metres or so, i.e., about 40 times sharper than the satellite map. Though the echo sounding data accounts for only 25% of the ocean mapped, this method is essential to accurately calibrate the altimetry data.

- Ask students to discuss the merits of the two data collection systems of ocean floor topography.

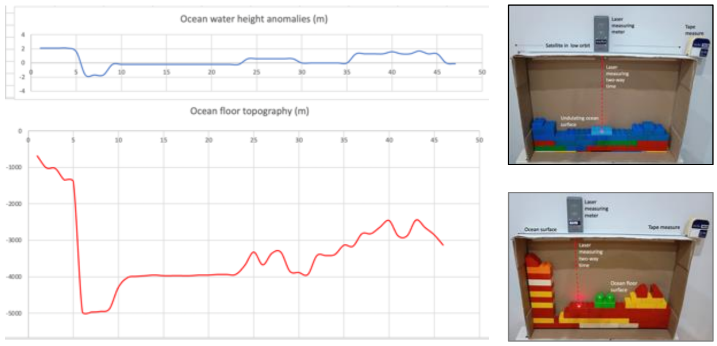

Fig **3**: The simulated ocean floor surface (Laser Quest 1) compared to ocean surface variations caused by gravitational forces (Laser Quest 2).

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The back up

Title: Laser Quest 2: above the waves.

Subtitle: Seeing evidence for plate tectonics beneath the oceans - using satellites

Topic: A simulation to demonstrate the principle behind satellite mapping of the ocean floor based on gravitational anomalies recorded at the ocean surface.

Age range of pupils: 15+ years

Time needed to complete activity: 20 minutes

Pupil learning outcomes: Pupils can:
- understand that different methods are used to measure the depth of the ocean floor (echo sounding and satellites);
- understand the principle of the two-way time method to measure variations in the height of the ocean surface caused by gravitational forces from the underlying ocean topography;
- use an analogue model to map a simulated ocean floor topography;
- draw a 2D graph of the model ocean surface variations using spreadsheet software or by hand;
- conclude the possible ocean floor topography from satellite data;
- verbally compare the characteristics of the echo sounding and satellite methods to other pupils;
- relate the inferred topographic profile to plate tectonic theory.

Context: This is the latest in a series of activities involving mapping the ocean floor that leads to the relationship between the topographic features and plate tectonic theory. The other activities are shown in the table on page 3.

Following up the activity: This activity is designed to follow on from Earthlearningidea 'Laser Quest 1 – below the waves' and may be used alongside other associated activities listed in the table below.

Underlying principles:
- Satellite altimetry is a technique in which radar pulses are reflected from the surface of the ocean to record the subtle variations in the ocean surface caused by gravitational differences that reflect the ocean floor topography beneath.
- Where there is an increase in gravity (above a seamount) a bulge occurs on the ocean surface as water is incompressible.
- Ocean height is calculated from the time it takes for a radar pulse to travel from a satellite transducer to the ocean surface and back; **two-way time**.
- Modern satellites in low orbit, such as the European Space Agency's 'Cryostats' (717 km altitude) or NASA's 'Jason' series (~1336 km altitude), have high enough precision to detect variations in ocean surface height to within a few centimetres.
- Each point on the ocean surface is measured every 10 days by the Jason 3 satellite.
- Once the data are corrected to isolate the gravitational effects caused by the mass anomalies from ocean floor features, scientists can construct an accurate global map of the ocean floor at low resolution. This is useful particularly in the 75% of ocean basins where echo sounding surveys have not yet reached.
- Depths obtained by echo sounding are a higher resolution and are used to calibrate the satellite measurements where tracks coincide.

Thinking skill development: Measuring and looking for patterns in the depth data is a construction activity, with possible cognitive conflict arising when unexpected values are calculated. Discussion among the class involves metacognition and linking the data and graphs to plate tectonic models uses bridging skills.

Resource list:
- laser distance meter measuring tool (simple battery-operated device)
- box/box lid
- suitable materials for constructing an ocean surface profile (e.g. Lego™)
- Spreadsheet software/graph paper.

Useful links:
https://www.geologybites.com/david-sandwell

Source:
Activity written by Pete Loader of the ELI Team for the EGU General Assembly 2025 GIFT Workshop.

The Earthlearningidea ocean floor mapping activities	
Measuring the depths of seas and oceans: How is it done? A simple demonstration of how we measure sea floor depths and relief	https://www.earthlearningidea.com/PDF/350_Sea_floor_mapping1.pdf
Modelling seafloor mapping: How to simulate an echo sounder study of seafloor topography	https://www.earthlearningidea.com/PDF/351_Sea_floor_mapping2.pdf
Sounding the Pacific Ocean: An echo sounder traverse of the eastern Pacific	https://www.earthlearningidea.com/PDF/352_Sea_floor_mapping3.pdf
Marie Tharp: 'The valley will be coming up soon'. Bruce Heezen: 'What valley?' A woman scientist in a man's world – what was it like?	https://www.earthlearningidea.com/PDF/353_Sea_floor_mapping4.pdf
Laser Quest 1 – below the waves. Seeing evidence for plate tectonics beneath the oceans using echo sounding	https://www.earthlearningidea.com/PDF/454_Laser_quest1.pdf
Laser Quest 2 – above the waves. Seeing evidence for plate tectonics above the oceans using satellites	https://www.earthlearningidea.com/PDF/456_Laser_quest2.pdf