Teaching waves with Google Earth

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Abstract

Google Earth is a huge source of interesting illustrations of various natural phenomena. It can represent a valuable tool for science education, not only for teaching geography and geology, but also physics. Here we suggest that Google Earth can be used for introducing in an attractive way the physics of waves.

Introduction

The physics of water waves is in general very complicated. Water waves are usually used as an example of waves in elementary courses, but as Feynman said ‘they are the worst possible example, because they are in no respect like sound and light; they have all the complications that waves can have’ [1].

For instance, since water is practically incompressible with pressure in play, a wave on the surface is not purely transverse: as the wave moves forward, water must move away from the trough to the crest, and the particles of water near the surface move approximately in circles.

Also, establishing the velocity of a water wave is not an easy theoretical question [2, 3]. If the depth of water is large (more than a wavelength) and the wavelength is long (more than a metre), the phase velocity of an approximately sinusoidal wave is proportional to the square root of the wavelength $\lambda$:

$$v_{\text{phase}} = \sqrt{\frac{g\lambda}{2\pi}}$$  \hspace{1cm} \text{(gravity waves)} \hspace{1cm} (1)

where $g$ is the gravitational acceleration. A wave with a longer wavelength goes faster than one with a shorter wavelength. For instance, the wind of a storm in the open sea produces waves of all lengths: waves with a long wavelength reach the beach first, waves with a shorter wavelength are slower and they arrive later. The same thing happens if it is a boat that makes waves: long waves of its wake arrive at the beach followed by shorter waves.

If waves are very short, like ripples in a ripple tank, the main force on them is not the gravitation but the surface tension. For such waves, denominated capillary waves, the phase velocity is

$$v_{\text{phase}} = \sqrt{\frac{2\pi T}{\lambda \rho}}$$  \hspace{1cm} \text{(capillary waves)} \hspace{1cm} (2)

where $T$ is the surface tension and $\rho$ the density of water. So, for this kind of wave, velocity is higher when the wavelength becomes shorter.

Capillary waves in water have wavelengths of a few cm or less. In general, we have both actions of gravity and surface tension, so the correct formula is more complicated and it has to contain both effects.

The group velocity can be deduced from the previous relations: it follows that for gravity waves the group velocity is less than the phase velocity, for ripples the group velocity is higher than the phase velocity. This is responsible for the different forms of wakes, such as those caused by a boat or a stick moving in water [4].

If the water is very shallow, when the depth $d$ is much less than a wavelength, we have to consider the friction effect of the sea floor. Then
another approximate formula for the velocity must be used for gravity waves:
\[ v_{\text{phase}} = \sqrt{gd}. \] (3)

Therefore, in shallow water, all waves travel with the same speed, which depends only on the depth of water. When the water depth decreases approaching the shore, the waves reduce their velocity.

In spite of the difficulty of the matter, many phenomena occurring on water surfaces can be qualitatively described with the same principles of wave physics taught at school and with just a few concepts introduced as above.

As already suggested in this review and elsewhere, Google Earth can be of valuable help in teaching physics [5–7].

Young pupils usually find the images of wave phenomena on the surface of the sea, lakes or rivers, much more interesting than pictures in books, normally taken from experiments with a ripple tank or just drawn.

For this reason, we think that Google Earth pictures can help to introduce in an effective way some fundamental concepts of wave physics [8].

For instance, we can find a lot of beautiful illustrations of phenomena such as reflection, refraction, diffraction and interference.

A few examples

According to Huygens’ principle [9], a wavefront which hits the points of a medium makes these points centres of new disturbances and sources of secondary waves. The amplitude of a secondary wave is at its maximum in the direction of propagation and decreases to zero towards the perpendicular direction.

We can imagine a wavefront constituted by many Huygens’ secondary waves. When a point at the front hits an obstacle or another point of the medium, that point becomes the source of another secondary circular wave. So we can describe the spreading out of waves when they go through an opening or why they can overshoot an obstacle.

We observe these diffraction phenomena when the wavelength is comparable with the dimensions of the obstacle.

For instance, in figure 1 we have an example of diffraction that reminds us of the single slit experiment: the protection barriers of the port diffract approximately plane waves into circular waves.

The diffracted waves distribute their energy in circular wavefronts. This produces the circular erosions on the beach shown in figure 2.
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Figures 3 and 4 are other examples of how waves can go beyond obstacles because of diffraction.

If waves reach an area where the water is shallower the friction with the bottom makes them slow down, see formula (3). Waves in shallower water propagate more slowly and their wavelength decreases. They can change direction and be subject to refraction. When wavefronts go forward to a straight shoreline at a certain angle, they bend and tend to become parallel to the line of the beach. An example of such refraction is represented in figure 5.

A tool of Google Earth allows us to measure the distance between two geographical points. So students can measure the wavelength and calculate the wave speed in deep water by applying equation (1). For instance, for $\lambda = 100$ m we have $v_{\text{phase}} = 12.5$ m s$^{-1}$.

If it is possible to estimate the depth of water, students can also calculate the speed in shallow...
water with equation (3). For instance, with $d = 1\, \text{m}$ we get $v_{\text{phase}} = 3.1\, \text{m} \, \text{s}^{-1}$.

When waves encounter an obstacle such as a cliff or a wall, they reflect back upon themselves. Figures 6 and 7 are examples of reflections.

Examining Google Earth images students can verify the law of reflection: the angle of incidence of waves equals the angle of reflection.

Sometimes reflected waves interfere with oncoming waves, as we can observe in these pictures (in shallow water also refraction and diffraction are often combined together as probably happens, for instance, in figure 3).

The overlap of two crests or two troughs makes a crest or a trough even bigger. The overlap of a crest with a trough causes a cancellation of the wave perturbation. This is the interference between waves which we can see in figures 8 and 9. Figure 9 may be an amusing example of a two slit experiment.

### Conclusions

Students can search out their own examples of wave phenomena on Google Earth. This is very instructive and entertaining for them. They, together with their teachers, can compare their own pictures with the traditional images in textbooks. Teachers could suggest looking for waves near big towns on the sea coast, big harbours, marina resorts and big rivers.

### References

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