Internal waves

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Internal waves in the atmosphere

The atmosphere is arranged in layers: layers with different temperature, humidity, and density that may be carried by winds in different directions. Unstable internal waves may develop over minutes at the interface between layers. The crests of these waves are cooler, often leading to condensation that forms clouds in regular bands. The clouds form in what is known as a K-H instability after Lord Kelvin and Professor Helmholtz who described the effect in the nineteenth century. K-H instability can be observed in a long slightly tilted water tank, but the apparatus takes time build, the demonstration takes time to set up, and the effect is fleeting.

Fig 1 - Mid to high level cloud modified by an internal wave.

As the amplitude of an internal wave becomes larger the wave breaks into turbulent eddies and may form what is known as a K-H instability cloud like that shown on the banner above. The colored cloud is forming at the interface between two wind layers in an internal wave that has increased in amplitude and is beginning to break into turbulent eddies. Wavelength dependent diffraction of sunlight by tiny recently formed droplets of similar size is responsible for the colors.

The images from Thailand in figures 1-3 are taken from the cloud atlas at … https://www.flickr.com/photos/jacobs_ian/albums/72157631779691323

Fig 2 – Cloud swept into turbulent breaking eddies at a K-H instability.

The clouds shown in figure 2 were short-lived but very often fossil-cloud persists long after the disturbance has subsided. Figure 3 shows fossil-cloud that originally formed in a K-H instability.

Fig 3 – Cloud that was originally formed into regular eddies in a K-H instability. Formations of this type are called billow clouds.

Internal waves in the sea

The speed of gravity waves on deep water is given by ...

$$v = \sqrt{\frac{g\lambda}{2\pi}}$$

The speed of internal gravity waves at the boundary between fresh water above and salt water of greater density below is proportional to the square root of the effective gravity constant g'.

$$g' = g(\rho_2 - \rho_1)/\rho_o$$

> ... where ρ_1 and ρ_2 are the densities of the upper and lower liquids respectively and ρ_o is the mean density $(\rho_1 + \rho_2)/2$. When the densities are very similar ρ_1 approaches ρ_2 and the propagation velocity is very low.

Note: *when returning by air from NZ to Bangkok on the 22nd of May 2005 the writer watched a regular series of 12-15 internal waves of perhaps 600 meter wavelength in the sea between Java and Bali. The internal waves were a kilometre or two off the coast of Java, between salt water below and fresh water above. They were clearly visible for several minutes as lighter (pale whitish) almost straight lines on the blue sea, but became invisible as the angle of observation changed and the sun no longer reflected from the interface. The internal waves appeared to be almost stationary, in contrast to slow moving surface swells of much shorter wavelength and different orientation that were visible on the surface nearby. There is no image of this event but images of similar waves are on the web.*

Dead water

The writer grew up in New Zealand and spent much of the first half of his life there, in a country surrounded by ocean in a windy temperate climate, ideal for small boats of all kinds.

The first time he sailed his six-metre yacht into the Kerikeri inlet was a little embarrassing. The pretty little boat was racing along healed over in the wind. Our hero on the tiller was smiling from ear to ear, when suddenly: she wallowed like a pig in mud. The speed crashed from 10 knots to one and he was out there floundering around wondering what had happened and who might be watching.

The problem he later found was dead water. A metre or more of fresh water over laid sea water in the inlet. The boat immediately generated a bow wave at the interface and then wallowed along on the back of that invisible slow moving internal wave.

Internal waves at a kerosene/water interface

The small rectangular tank has water below and kerosene with blue dye above. Moving the tank suddenly a few mm to the left generates standing waves in the tank that gradually reduce in amplitude. If the tank is placed on a rubber base the amplitude of the waves can be maintained indefinitely by hand.

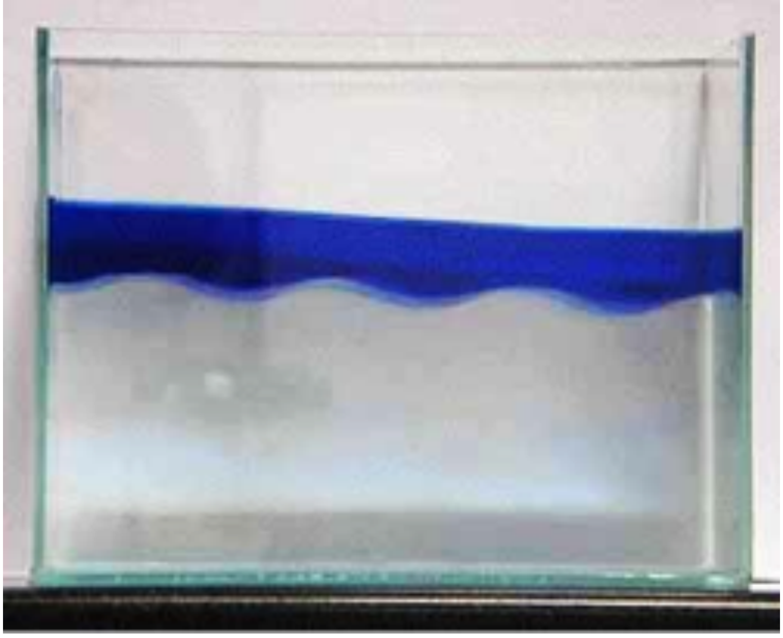

Fig 4 – two standing waves. The internal wave at the kerosene/water interface has a shorter wavelength but the same frequency.

The half wavelength standing wave on the upper surface (kerosene) has a wavelength of 2x20 cm. The internal standing wave at the kerosene/water interface has a wavelength of 2x20(2/7) cm. The depth of the layers has been adjusted so that both waves are excited when the tank is moved by hand to the right and to the left. The frequency adjustment is a second order effect, possible because the deep layer approximation above does not apply exactly in this case.

Projects

1 *Carry a camera at all times. Watch the sky. Photograph clouds. Look for K-H instability in low-lying fog, mid-level altocumulus and high-level cirrus (ice cloud). Compile and publish a cloud atlas.*

2 *Make an executive toy like that shown in figure 4 above with a glass tank, kerosene, water and dye. Seal the top carefully when finished to avoid the smell of kerosene. Do the math: write a paper.*