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# How much can a mode-2 wave move?

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Look out over the ocean and you might get the impression that it's a mass of water acting as a single entity. However, the world's oceans are made up of layers of different densities, called stratifications, with complex fluid dynamics. Often bulges, called mode-2 internal waves, form in the thickness of these layers, trapping materials inside that then move along with the wave.

For the first time, two mathematicians at Canada's University of Waterloo have created a 3-D simulation of the mass transport capabilities of mode-2 waves. Such models will help define how mode-2 waves can carry materials that are either beneficial (such as phytoplankton and other food sources) or detrimental (such as crude oil and other contaminants) between ecosystems.

The simulation is described this week in *Physics of Fluids*.

In the physical analog of their simulation, the researchers create a stratification by placing fluids of different densities behind a physical gate. After the fluids have mixed a bit, a stratification remains, consisting of dense water sitting below a layer of less dense water. Sometimes, a third thin layer of medium density, known as a double pycnocline, is trapped between the other two.

"When the fluid behind the gate is mixed and then the gate is removed, the mixed fluid collapses into the stratification because it is both heavier than the top layer and lighter than the bottom one," said David Deepwell, a Waterloo graduate student in applied mathematics. "Adding dye to the mixed fluid while the gate is in place simulates the material we want the mode-2 waves—the bulges in the pycnocline formed once the gate is taken away—to transport. We can then measure the size of the wave, how much dye remains trapped within it, and how well the wave carries its captured material."

Deepwell and his supervisor, mathematician Marek Stastna, found that the larger the bulge, the more material carried by the mode-2 internal wave. They also discovered that small regions of turbulence, called lee instabilities, can form behind the wave, and that these can cause the wave to break down.

"We believe what happens is that a vorticity dipole—two vortices close together and spinning in opposite directions—leads to these lee instabilities, because it forces some heavy fluid to go above the lighter fluid, which is the reverse of the condition that forms the mode-2 internal wave in the first place," Deepwell said.

Deepwell and Stastna also discovered an optimal scenario in which the mode-2 internal wave survives and then transports material as long as possible, and they uncovered the properties of a specific type of wave that they previously dubbed the Pac-Man.

"When [a Pac-Man] forms, the dye takes on the shape of the arcade game character," Deepwell said.

Having studied the interior of the mode-2 internal wave, the researchers will next look at how the whole wave breaks down.

"We will examine how the energy of the wave is deposited when it is destroyed," Deepwell said.

**More information:** "Mass transport by mode-2 internal solitary-like

waves," David Deepwell and Marek Stastna, *Physics of Fluids*, May 24, 2016. DOI: 10.1063/1.4948544

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