What Earth's climate system and topological insulators have in common

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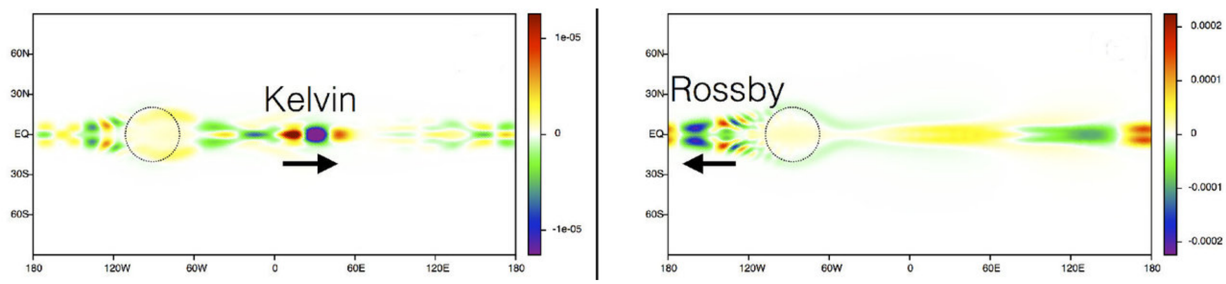

New research shows that equatorial waves -- pulses of warm ocean water that play a role in regulating Earth's climate -- are driven by the same dynamics as the exotic materials known as topological insulators. Equatorial Kelvin waves, which are responsible for the El Nino-Southern Oscillation, travel from West to East. Another type of equatorial wave--Rossby waves--move in the opposite direction. Credit: Deplace/Marston/Venaille

Topological insulators, materials that insulate on the inside but conduct electricity along their outer edges, have created quite a buzz in condensed matter physics. Now a new study in the journal *Science* shows that the same topological behavior that governs these exotic materials also drives equatorial waves—pulses of warm ocean water that play a major role in regulating the Earth's climate, including the El Niño-Southern Oscillation.

"These waves were discovered by geophysicists in the 1960s, but they lacked a deep understanding of why they existed," said Brad Marston, a physics professor at Brown University and coauthor of the new study. "What we've shown is that they have the same origin as the waves that are important in solid state physics—the waves of electrons that travel around the edges of topological insulators."

The research was inspired by a special type of topological insulator that exhibits what's known as the quantum Hall effect, which was discovered in 1980. The topology plays an essential role in the quantum Hall effect was recognized by the 2016 Nobel Prize in physics that was awarded to trio of physicists, including Brown University's Michael Kosterlitz.

In the quantum Hall effect, a magnetic field causes electrons inside a semiconducting material to travel in circles called cyclotron orbits. That circular movement prevents a flow of electrons—a current—from moving across the material, except at the material's outer edges. There, electrons can only complete a half-circle before running out of real estate and banging against the edge. Because all of the electrons on a given edge execute their movement in the same direction, all those half-circles can link up and form an edge current. Thus, topological insulators conduct on the outside and insulate on the inside.

Marston and his collaborators, Pierre Delplace and Antoine Venaille from the University of Lyon in France, showed that analogous dynamics are at play with Earth's equatorial waves. In the case of the Earth, the role of the magnetic field is played by the Coriolis effect—an apparent force caused by the planet's rotation. It's what causes hurricanes to spin in opposite directions in the Northern and Southern hemispheres. The role of the edge is played by the equator, where the Coriolis force breaks down.

"In each of the two hemispheres, you have the Coriolis force pushing in opposite directions," Marston said. "That traps the waves at the equator in a way that's very similar to how the current in a topological insulator is trapped at its edges. While the Earth doesn't have an 'edge' per se, the equator is essentially the edges of the two hemispheres stuck together."

The mathematics behind the two phenomena, Marston and his colleagues showed, is essentially identical.

"If you look in recent solid state physics papers at diagrams that describe the dispersion of electrons in a topological insulator, the plots looks exactly like the diagram in a geophysics textbook that depicts the dispersion of equatorial waves," Marston said. "When topological insulators were discovered a decade ago it was new physics, but to our surprise the Earth has been doing it all along."

The research helps to explain the existence of several types of equatorial waves. One of them, known as the equatorial Kelvin wave, delivers periodic pulses of warm water to the coast of South America, which is the El Niño oscillation. The findings also explain how these waves persist despite being battered by storms and shifting wind, and how they pass straight by islands that might be expected to cause the waves to scatter.

"In topological insulators, the current is able to move right through impurities in the material as if they weren't there," Marston said. "That's because of their topological nature, and it helps us understand why equatorial waves and the El Niño oscillation persist despite being jostled around by weather and other obstacles."

In addition to helping explain the persistence of El Niño cycles, Marston says these same dynamics are likely happening elsewhere in the climate system—in the upper atmosphere, for example. Recognizing the topological nature of these phenomena could help deepen scientists' understanding of how they work, Marston says.

"As a practical matter, this will give us new ways to identify these kinds of climate dynamics by looking at the topology," he said. "We might be able to find and understand topological structures that may have been missed before."

More information: "Topological origin of equatorial waves" *Science* (2017). science.sciencemag.org/lookup/ … 1126/science.aan8819

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