'The ocean remembers': Study suggests ocean maintained relatively steady temperature through most of 20th century

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In estimations of ocean heat content—important when assessing and predicting the effects of climate change—calculations have often presented the rate of warming as a gradual rise from the mid-20th century to today. However, new research from UC Santa Barbara scientists Timothy DeVries and Aaron Bagnell could overturn that assumption, suggesting the ocean maintained a relatively steady temperature throughout most of the 20th century, before embarking on a

steep rise. The newly discovered dynamics may have significant implications for what we might expect in the future.

"There wasn't an onset of an imbalance until about 1990, which is later than most estimates," said DeVries, an associate professor in the Department of Geography, and a co-author on a paper that appears in the journal *Nature Communications*. According to the study, the period from 1950 to 1990 saw temperature fluctuations in the water column but no net warming. After 1990, the study continues, the entire water column switched from cooling to warming.

These findings are the result of the addition of a largely underexplored factor in ocean heat content (OHC): Deep ocean temperatures.

"Prior studies didn't consider the deep ocean," said Bagnell, a graduate scholar in DeVries's laboratory and the paper's lead author. Because of the challenges involved in getting temperature measurements in the deep ocean (below 2,000 meters) that region has gone largely unaccounted for, and data has been sparse. "There is some existing data, from research cruises and autonomous floats," he added.

The researchers used an autoregressive artificial neural network (ARANN) and machine learning methods to connect the dots between data points and "produce a single consistent estimate of the top-to-bottom OHC change for 1946 to 2019." The result was a trend that delays warming by decades over previous models.

There are two main possibilities for why the effects of global warming took so long to reach the ocean, De Vries said.

"One is that anthropogenic warming might have been weaker than previously thought during the 20th century, perhaps due to the cooling effects of aerosol pollution," he said. The other is that the deep ocean

may still be exhibiting the effects of climate events long past.

"It can take centuries for climate signals to propagate from the surface to the interior," he said. Thus, the effects of a cooling event such as the Little Ice Age might be deep history to us on the surface, but the echoes of the event may have continued to resonate in the deep ocean into the 20th century, providing a buffer to the warming Earth.

The delayed cooling effect ended in 1990, after which ocean temperatures, according to the study, have been accelerating upward.

"The lag is catching up and the ocean is warming more strongly now," Bagnell said. The Atlantic Ocean and Southern Ocean are currently where most of the warming is, with the Pacific Ocean and Indian Ocean not far behind.

Ocean warming is a concern on many levels, as it can cause changes in circulation, reduce its ability to absorb carbon and fuel more intense storms, in addition to causing sea level rise and creating inhospitable environments for undersea life. If the trend continues, the effects might last centuries, thanks to the same lag that kept the oceans cool until the last 30 years.

"The ocean remembers," DeVries said.

More information: A. Bagnell et al, 20th century cooling of the deep ocean contributed to delayed acceleration of Earth's energy imbalance, *Nature Communications* (2021). DOI: 10.1038/s41467-021-24472-3

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