Study removes human bias from debate over dinosaurs' demise

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Credit: Pixabay/CC0 Public Domain

To help resolve the scientific debate over whether it was a giant asteroid or volcanic eruptions that wiped out the dinosaurs and most other species 66 million years ago, Dartmouth researchers tried a new approach—they removed scientists from the debate and let the computers decide.

The researchers report a new modeling method powered by interconnected processors that can work through reams of geological and climate data without human input. The paper, "A Bayesian inversion for emissions and export productivity across the end-Cretaceous boundary," was published Sept. 29 by *Science*.

They tasked nearly 130 processors with analyzing the fossil record in reverse to pinpoint the events and conditions that led to the Cretaceous–Paleogene (K–Pg) extinction event that cleared the way for the ascendance of mammals, including the primates that would lead to early humans.

"Part of our motivation was to evaluate this question without a predetermined hypothesis or bias," said Alex Cox, first author of the study and a graduate student in Dartmouth's Department of Earth Sciences. "Most models move in a forward direction. We adapted a carbon-cycle model to run the other way, using the effect to find the cause through statistics, giving it only the bare minimum of prior information as it worked toward a particular outcome.

"In the end, it doesn't matter what we think or what we previously thought—the model shows us how we got to what we see in the geological record," he said.

The model crunched more than 300,000 possible scenarios of carbon dioxide emissions, sulfur dioxide output, and biological productivity in the 1 million years before and after the K–Pg extinction. Through a type of machine learning known as Markov Chain Monte Carlo—which is not unlike how a smartphone predicts what you'll type next—the processors worked together independently to compare, revise, and recalculate their conclusions until they reached a scenario that matches the outcome preserved in the fossil record.

Geochemical and organic remnants in the fossil record capture clearly the catastrophic conditions during the K–Pg extinction, so named for the geological periods on either side of the millennia-long cataclysm.

Animals and plants worldwide suffered massive die-offs as food webs collapsed under an unstable atmosphere that—laden with sun-blotting sulfur, airborne minerals and heat-trapping carbon dioxide—swung wildly from frigid to scorching conditions.

While the effect is clear, the cause of the extinction is unresolved. Early theories attributing the event to volcanic eruptions have been eclipsed by the discovery of an impact crater in Mexico known as Chicxulub that was caused by a miles-wide asteroid now thought to be primarily responsible for the extinction event. The theories have begun to converge, however, as fossil evidence suggests a one-two punch unlike anything in Earth's history: The asteroid may have slammed into a planet already reeling from the massive, extremely violent eruptions of volcanoes in western India's Deccan Traps.

But scientists still do not know—nor agree on—the extent to which each event contributed to the mass extinction. So, Cox and his adviser Brenhin Keller, a Dartmouth assistant professor of Earth sciences and study co-author, decided to "see what you would get if you let the code decide."

Their model suggested that the outpouring of climate-altering gases from the Deccan Traps alone could have been sufficient to trigger the global extinction. The Traps had been erupting for roughly 300,000 years before the Chicxulub asteroid. During their nearly 1 million years of eruptions, the Deccan Traps are estimated to have pumped up to 10.4 trillion tons of carbon dioxide and 9.3 trillion tons of sulfur into the atmosphere.

"We've known historically that volcanoes can cause massive extinctions, but this is the first independent estimation of volatile emissions taken from the evidence of their environmental effects," said Keller, who published a paper last year linking four of Earth's five mass extinctions to volcanism.

"Our model worked through the data independently and without human bias to determine the amount of carbon dioxide and sulfur dioxide required to produce the climate and carbon cycle disruptions we see in the geologic record. These amounts turned out to be consistent with what we expect to see in emissions from the Deccan Traps," said Keller, who has worked extensively to examine the link between Deccan volcanism and the K–Pg extinction.

The model did reveal a steep drop in the accumulation of organic carbon in the deep ocean around the time of the Chicxulub impact, which likely resulted from the asteroid causing the demise of numerous animal and plant species. The record contains traces of a decrease in temperature around the same time that would have been caused by the large amount of sulfur—a short-term cooling agent—the mammoth meteorite would have ejected into the air when it collided with the sulfur-rich surface on that area of the planet.

The asteroid impact also would have likely emitted both carbon and sulfur dioxide. However, the model found that there was no spike in the emissions of either gas at that time, suggesting that the asteroid's contribution to the extinction did not hinge on gas emissions.

In modern context, Cox said, the burning of fossil fuels from 2000 to 2023 has pumped about 16 billion tons of carbon dioxide into the atmosphere per year. This is 100 times greater than the highest annual emission rate scientists project from the Deccan Traps. While alarming on its own, it would still take a few thousand years for current carbon dioxide emissions to match the total amount that spewed forth from the ancient volcanoes, Cox said.

"Most heartening is that the results we achieved are broadly physically plausible, which is impressive given that the model could have technically run completely wild without stronger prior constraints," he said.

Interconnecting the processors shortened the time it took the model to analyze such a massive data set from months or years to hours, Cox said. His and Keller's method can be used to invert other Earth systems models—such as those for the climate or carbon cycle—to evaluate geological events for which the outcomes are well known but not the factors that led there.

"This type of parallel inversion hasn't been done in Earth sciences models before. Our method can be scaled up to include thousands of processors, which gives us a much broader solution space to explore, and it's quite resistant to human bias," Cox said.

"So far, people in our field have been more fascinated by the novelty of the method than the conclusion we reached," he laughed. "Any Earth system for which we know the effect but not the cause is ripe for inversion. The better we know the output, the better we're able to characterize the input that caused it.

More information: Alexander A. Cox, A Bayesian inversion for emissions and export productivity across the end-Cretaceous boundary, *Science* (2023). DOI: 10.1126/science.adh3875. www.science.org/doi/10.1126/science.adh3875

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