

Exploring the intersection of AI and climate physics: Machine learning's role in advancing climate science

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Researchers launch a lightweight, balloon-borne instrument to collect data. "To keep advancing, we need scientists who can determine what data we need, collect that data, and solve problems," Bracco says. Credit: NOAA

Exponential growth in big data and computing power is transforming climate science, where machine learning is playing a critical role in mapping the physics of our changing climate.

"What is happening within the field is revolutionary," says School of Earth and Atmospheric Sciences Associate Chair and Professor Annalisa Bracco, adding that because many climate-related processes—from [ocean currents](#) to melting glaciers and [weather patterns](#)—can be described with physical equations, these advancements have the potential to help us understand and predict climate in critically important ways.

Bracco is the lead author of a new review paper providing a comprehensive look at the intersection of AI and climate physics.

The result of an international collaboration between Georgia Tech's Bracco, Julien Brajard (Nansen Environmental and Remote Sensing Center), Henk A. Dijkstra (Utrecht University), Pedram Hassanzadeh (University of Chicago), Christian Lessig (European Center for Medium-Range Weather Forecasts), and Claire Monteleoni (University of Colorado Boulder), the paper, "Machine learning for the physics of climate," was recently [published](#) in *Nature Reviews Physics*.

"One of our team's goals was to help people think deeply on how [climate science](#) and AI intersect," Bracco shares. "Machine learning is allowing us to study the physics of climate in a way that was previously impossible. Coupled with increasing amounts of data and observations, we can now investigate climate at scales and resolutions we've never been able to before."

Connecting hidden dots

The team showed that ML is driving change in three key areas: accounting for missing [observational data](#), creating more robust climate

models, and enhancing predictions, especially in weather forecasting. However, the research also underscores the limits of AI—and how researchers can work to fill those gaps.

"Machine learning has been fantastic in allowing us to expand the time and the spatial scales for which we have measurements," says Bracco, explaining that ML could help fill in missing data points—creating a more robust record for researchers to reference. However, like patching a hole in a shirt, this works best when the rest of the material is intact.

"Machine learning can extrapolate from past conditions when observations are abundant, but it can't yet predict future trends or collect the data we need," Bracco adds. "To keep advancing, we need scientists who can determine what data we need, collect that data, and solve problems."

Modeling climate, predicting weather

Machine learning is often used when improving [climate models](#) that can simulate changing systems like our atmosphere, oceans, land, biochemistry, and ice. "These models are limited because of our computing power, and are run on a three-dimensional grid," Bracco explains. Below the grid resolution, researchers need to approximate complex physics with simpler equations that computers can solve quickly, a process called "parameterization."

Machine learning is changing that, offering new ways to improve parameterizations, she says. "We can run a model at extremely high resolutions for a short time, so that we don't need to parameterize as many [physical processes](#)—using [machine learning](#) to derive the equations that best approximate what is happening at small scales," she explains. "Then we can use those equations in a coarser model that we can run for hundreds of years."

While a full climate model based solely on machine learning may remain out of reach, the team found that ML is advancing our ability to accurately predict weather systems and some climate phenomena like El Niño.

Previously, weather prediction was based on knowing the starting conditions—like temperature, humidity, and [barometric pressure](#)—and running a model based on physics equations to predict what might happen next. Now, machine learning is giving researchers the opportunity to learn from the past.

"We can use information on what has happened when there were similar starting conditions in previous situations to predict the future without solving the underlying governing equations," Bracco says. "And all while using orders-of-magnitude less computing resources."

The human connection

Bracco emphasizes that while AI and ML play a critical role in accelerating research, humans are at the core of progress. "I think the in-person collaboration that led to this paper is, in itself, a testament to the importance of human interaction," she says, recalling that the research was the result of a workshop organized at the Kavli Institute for Theoretical Physics—one of the team's first in-person discussions after the COVID-19 pandemic.

"Machine learning is a fantastic tool—but it's not the solution to everything," she adds. "There is also a real need for human researchers collecting high-quality data, and for interdisciplinary collaboration across fields. I see this as a big challenge, but a great opportunity for computer scientists and physicists, mathematicians, biologists, and chemists to work together."

More information: Annalisa Bracco et al, Machine learning for the physics of climate, *Nature Reviews Physics* (2024). [DOI: 10.1038/s42254-024-00776-3](https://doi.org/10.1038/s42254-024-00776-3)

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