New 'digital twin' Earth technology could help predict water-based natural disasters before they strike

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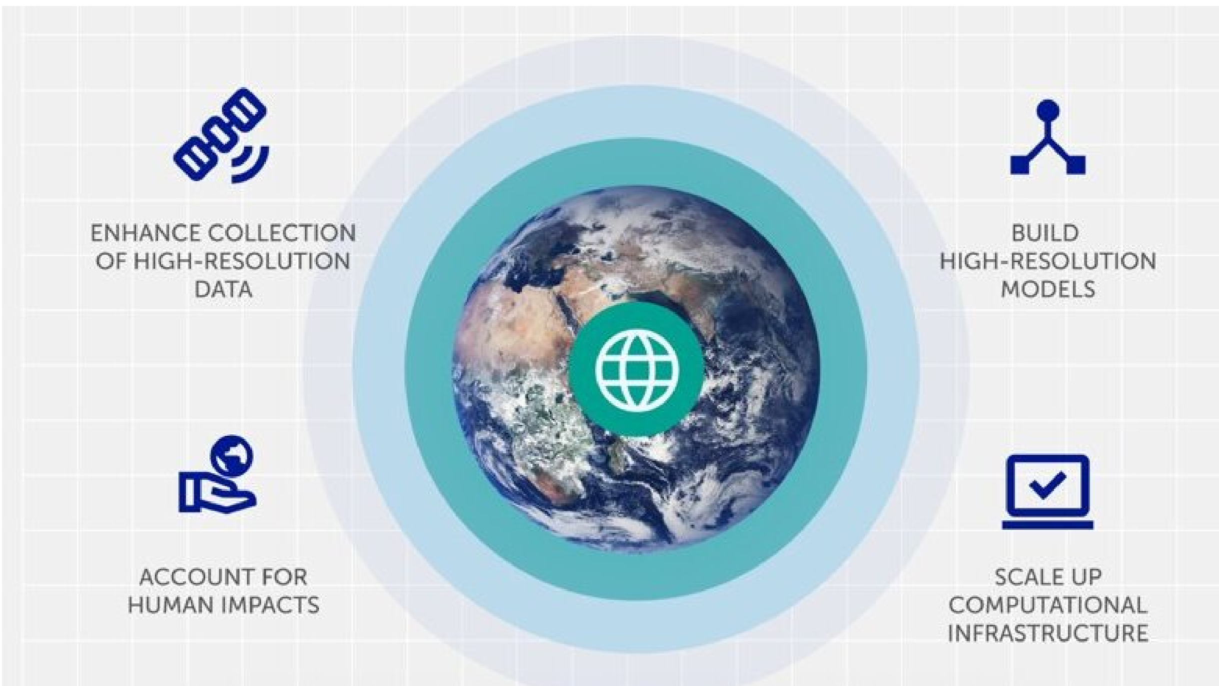


Key milestones for creating a planetary-scale Digital Twin Earth. Credit: Brocca L et al/Frontiers

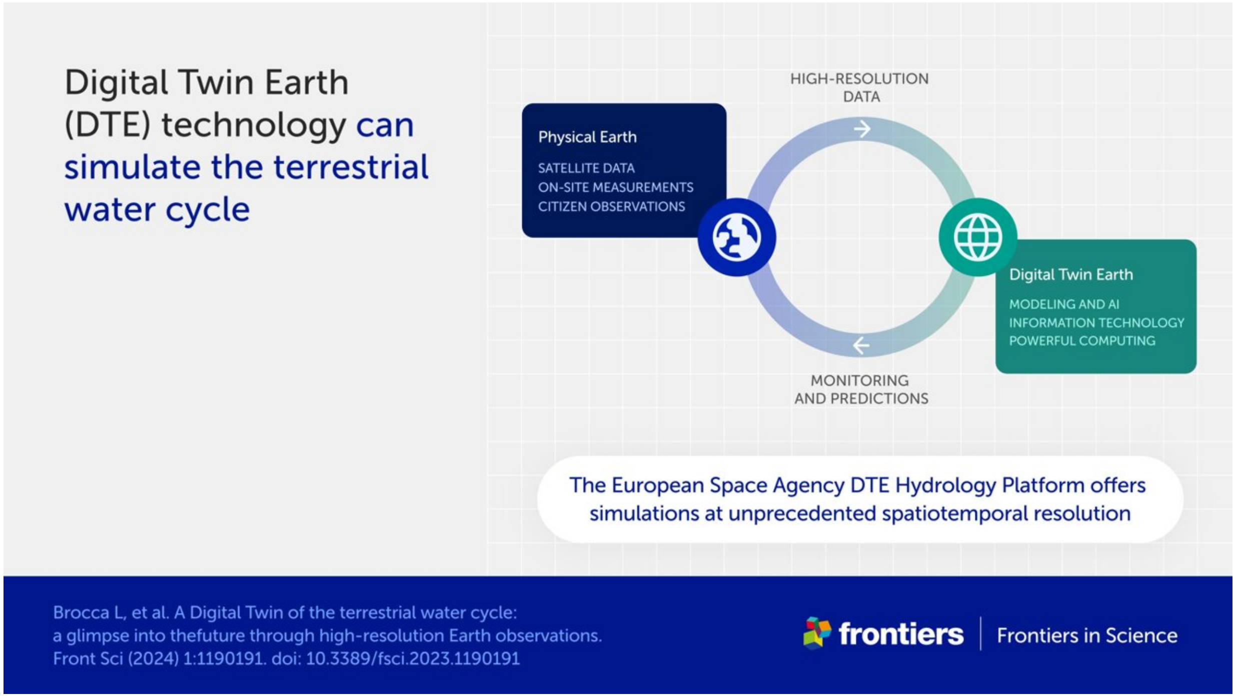
The water cycle looks simple in theory—but human impacts, climate change, and complicated geography mean that in practice, floods and droughts remain hard to predict. To model water on Earth, you need incredibly high-resolution data across an immense expanse, and you need modeling sophisticated enough to account for everything from snowcaps on mountains to soil moisture in valleys. Now, scientists have made a tremendous step forward by building the most detailed models created to date.

"Simulating the Earth at high resolution is very complex, and so basically the idea is to first focus on a specific target," said Dr. Luca Brocca of the National Research Council of Italy, lead author of the article published in *Frontiers in Science*. "That's the idea behind what we have developed—digital twin case studies for the terrestrial water cycle in the Mediterranean Basin. Our goal is to create a system that allows non-experts, including decision-makers and citizens, to run interactive simulations."

A test environment for the planet

In engineering, a digital twin is a virtual model of a physical object which can be tested to destruction without doing real damage. A digital twin of the Earth, constantly updated with new data, would allow us to simulate best and worst-case scenarios, assess risks, and track the development of dangerous conditions before they occur. Such information is vital for sustainable development and protecting vulnerable populations.

To build their digital twin models, Brocca and his colleagues harnessed extraordinary volumes of satellite data, combining new Earth observation data that measures soil moisture, precipitation, evaporation, river discharge, and snow depth. This newly available data, crucial to the development of the models, includes measurements taken much more frequently across space and time: as often as once a kilometer and once an hour.



Digital Twin Earth technology can simulate the terrestrial water cycle. Credit: Brocca L et al/Frontiers

Like a screen with more pixels, this higher-resolution data creates a more detailed picture. The scientists used this data to develop their modeling, and then integrated the modeling into a cloud-based platform which can be used for simulations and visualizations. This is the ultimate goal: an interactive tool anyone can use to map risks like floods and landslides and manage water resources.

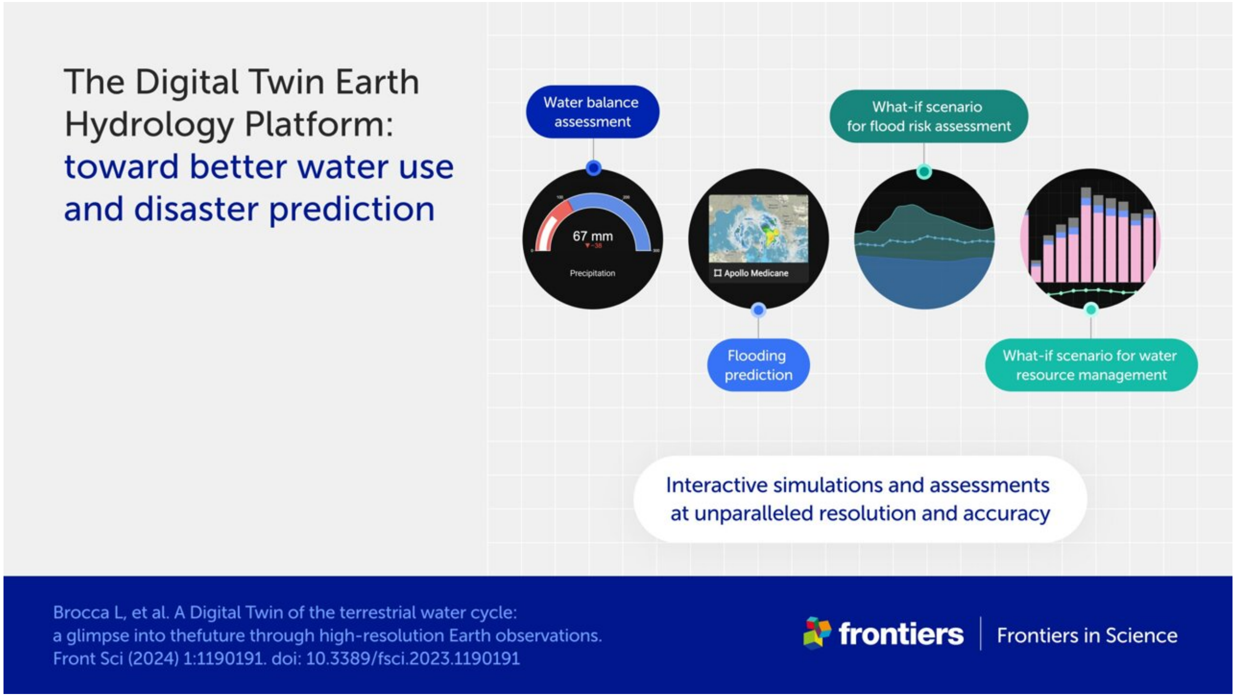
"This project is a perfect example of the synergy between cutting-edge satellite missions and the scientific community," said Brocca. "Collaborations like this, coupled with investments in computational infrastructures, will be crucial for managing the effects of climate change and other human impacts."

Helping people plan the future

The scientists began by modeling the Po River valley, then expanded the digital twin to other parts of the Mediterranean basin. Upcoming projects plan to expand to cover all of Europe, and future collaborations will allow the same principles to be applied around the world.

"The story started with an initiative from the European Space Agency," said Brocca. "I said we should start from something we know very well. The Po River valley is very complex—we have the Alps, we have snow, which is difficult to simulate, especially in irregular and complex terrain like mountains. Then there is the valley with all the human activities—industry, irrigation. Then we have a river and extreme events—floods, drought. And then we moved to the Mediterranean, which is a good place to investigate extreme events both for too much and too little water."

The platform's primary use-case is to enhance flood and landslide prediction and optimize water resource management. To make this work better on a more local level, more granular data and more sophisticated modeling will be needed. For instance, to maximize the potential of a digital twin for agriculture, data resolution should be measured in tens of meters, not hundreds.



The Digital Twin Earth hydrology platform: toward better water use and disaster prediction. Credit: Brocca L et al/Frontiers

Known unknowns

Additional challenges persist. These include delays in the transfer of satellite data to the model, the need for more ground observations to validate satellite data, and the increasing complexity of the algorithms needed to handle the data.

Furthermore, no model is perfect, and satellite data can contain errors: uncertainties must be properly characterized so that users have an accurate picture of the model's reliability. According to Brocca, artificial intelligence and machine learning will have a pivotal role in overcoming these challenges, by enhancing data analysis, collection, and processing speed, and streamlining data quality assessment.

"The collaborative efforts of scientists, space agencies, and decision-makers promise a future where Digital Twin Earths for hydrology provide invaluable insights for sustainable water management and disaster resilience," Brocca concluded.

More information: A Digital Twin of the terrestrial water cycle: a glimpse into the future through high-resolution Earth observations, *Frontiers in Science* (2024). DOI: 10.3389/fsci.2023.1190191

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