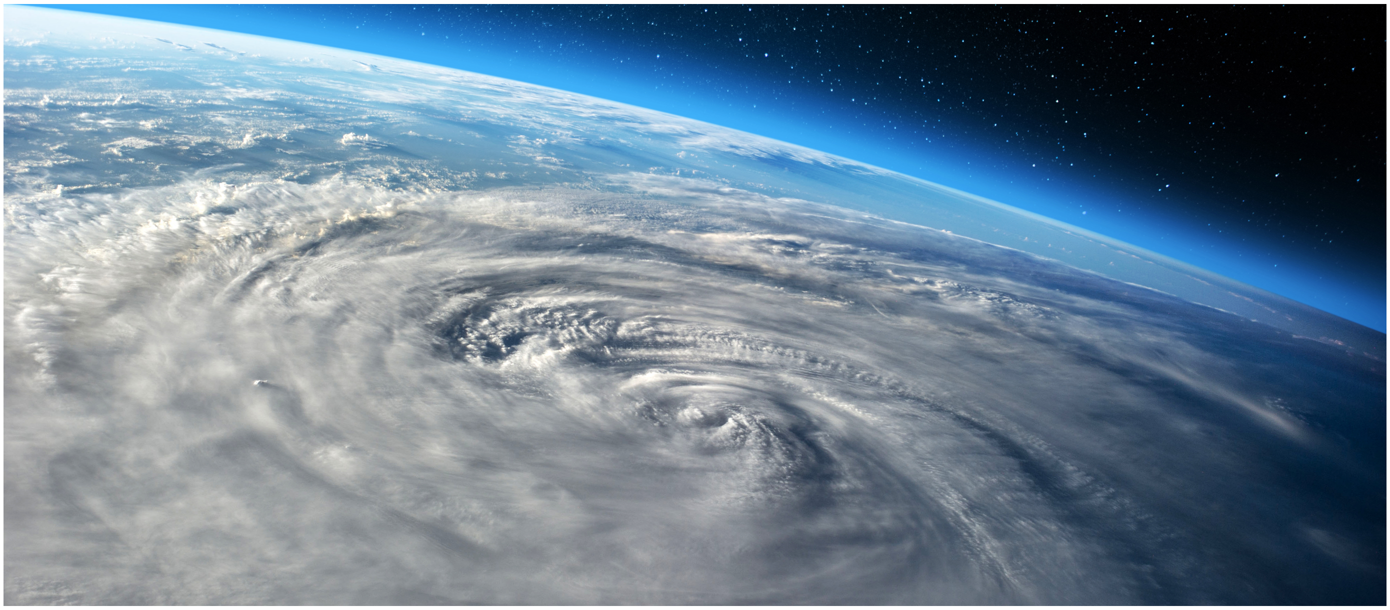

Bringing Computation to the Climate Challenge

Anthropogenic climate change is upon us. Even with mitigation strategies, it will require us to adapt infrastructure such as water reservoirs and flood control measures to a new normal. But it is unclear what the new normal will be.

Projections of climate change and of the risk of climate hazards remain uncertain, and the uncertainties themselves are inadequately quantified. The climate models used to make the projections are complex and often replaced with even less accurate surrogate models to make decisions on the ground. There is a growing concern that these tools are not fit for purpose and will hamper informed decision-making, which will cost society a chance to adapt proactively and effectively.

We propose developing a novel platform that leapfrogs existing climate decision-support tools by leveraging advances in computational and data sciences and in the availability of Earth observations from space and from the ground. This platform will improve the accuracy of climate models, quantify their uncertainty, and conveniently provide an optimal trade-off between performance and computation time suited for stakeholder needs.

OBJECTIVES AND PROPOSED SOLUTIONS

Objective 1. Build a digital twin of the Earth system.

Digital twins are numerical models of a real system that are continuously updated from real-time data using machine learning and reasoning to aid decision making. MIT, in collaboration with Caltech, has begun to build a digital twin of the Earth that capitalizes on advances in data assimilation and machine learning to develop a climate model that automatically learns from global observations from space and the ground and from data generated computationally in high-resolution simulations. The digital twin includes the physics of the atmosphere, ocean, and land. As part of this proposal, we would develop the sea/land ice and biogeochemistry components of the digital twin, which are crucial to studies of sea-level rise and carbon emission impacts. We will also develop the capability to automatically launch high-resolution simulations to deliver on-demand, reliable, localized projections of climate impacts such as changes in rainfall extremes or droughts.

Objective 2. Develop tailored surrogate models.

These surrogate models will be tailored to predict only a subset of climate variables of interest in a particular mitigation/adaptation study, like hurricane risk in Florida or flood risk in Bangladesh. While simplified reduced-form models exist and are currently used by decision makers, these models rely on expert tuning and typically lag state-of-the-art climate models by at least one generation—if not more. The innovation we propose is to leverage artificial intelligence techniques for model reduction to generate digital cousins of the Earth digital twin that maintain the highest possible accuracy in predicting the variables of interest, while also providing a quantitative estimate of the uncertainty in those predictions.

Objective 3. Identify appropriate test cases.

We will work with stakeholders to identify test cases where we can apply our software platform in software tools used for assessing risks of climate hazards and potential adaptation strategies. To this end, our team includes MIT groups that provide a bridge to communities that need climate-related information, many of which use existing reduced-complexity approaches for bridging science to action. We anticipate an iterative process in which stakeholders provide input as simulations are designed and implemented. We will organize a number of workshops early in the project to identify test cases that are a good match for our team and ripe to be tackled with our emerging tools.

Objective 4. Develop and teach an undergraduate class that combines computational thinking and climate science.

This class will be based on our new software platform, which is very user friendly and being written in the Julia language developed at MIT. Our goal is to inspire MIT students to engage in planning a resilient society using the most accurate and actionable climate science information.

Summary

The digital twin and cousin platform represents radical innovation in climate modeling. It will set a new paradigm for climate modeling and will provide outsize benefits to society. Our software tools tailored to stakeholder needs will provide the basis for data-driven decisions about climate-related infrastructure investments and disaster preparedness—an outcome that is estimated to be worth trillions of dollars in socioeconomic value.

TEAM EXPERTISE AND LEADERSHIP

The team includes 14 professors and researchers with broad expertise in climate science, numerical models of the Earth system, high-performance computing, machine learning and artificial intelligence, global health impacts of climate, and science-policy interactions. We will also work in close collaboration with the Climate Modeling Alliance at Caltech.

The two team leaders are:

- **Raffaele Ferrari**: expertise in climate science and modelling, parameterization of subgrid scale processes in climate models, machine learning techniques for turbulence modeling
- **Noelle Eckley Selin**: expertise in climate science and modelling, atmospheric chemistry, air quality, sustainability analysis, and science-policy interactions