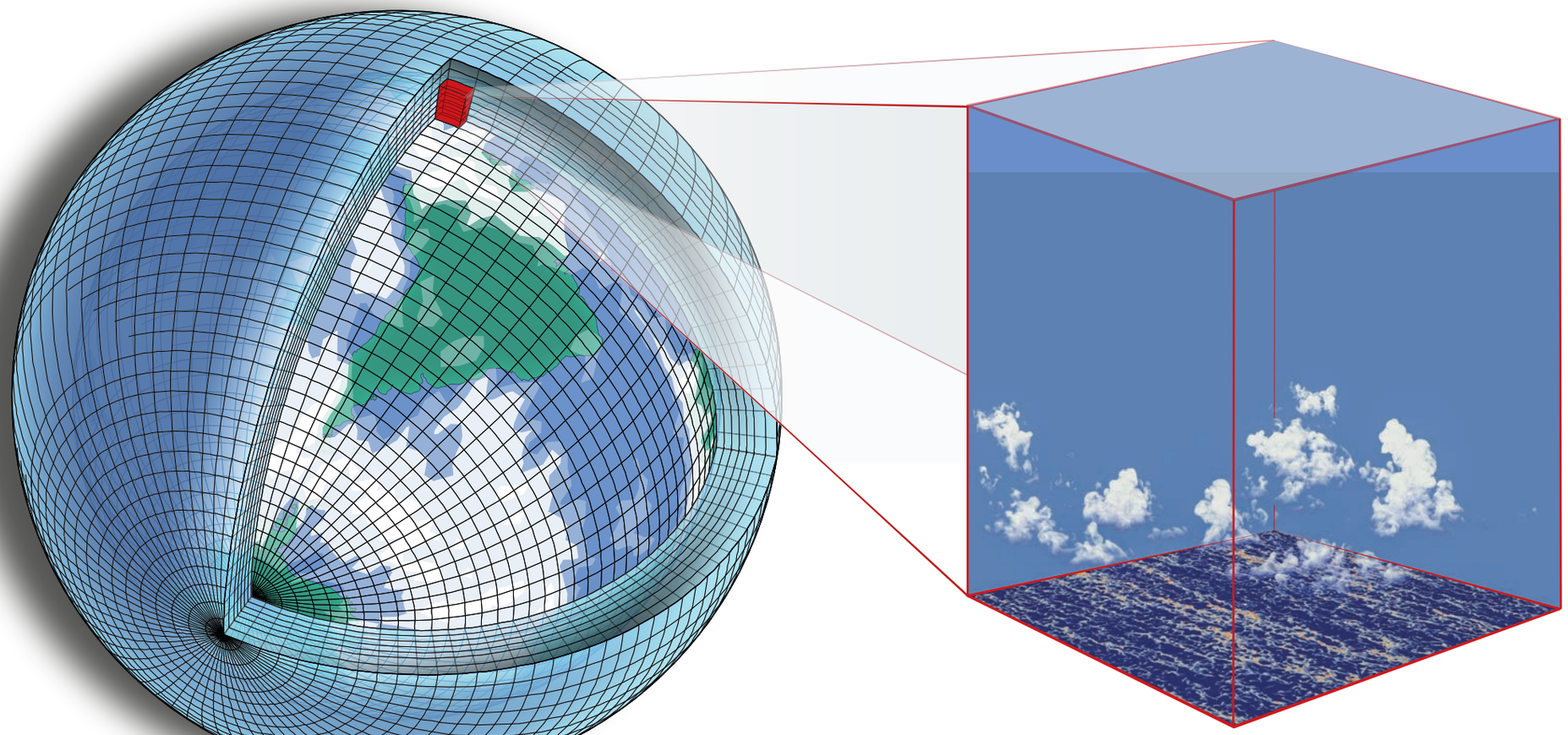
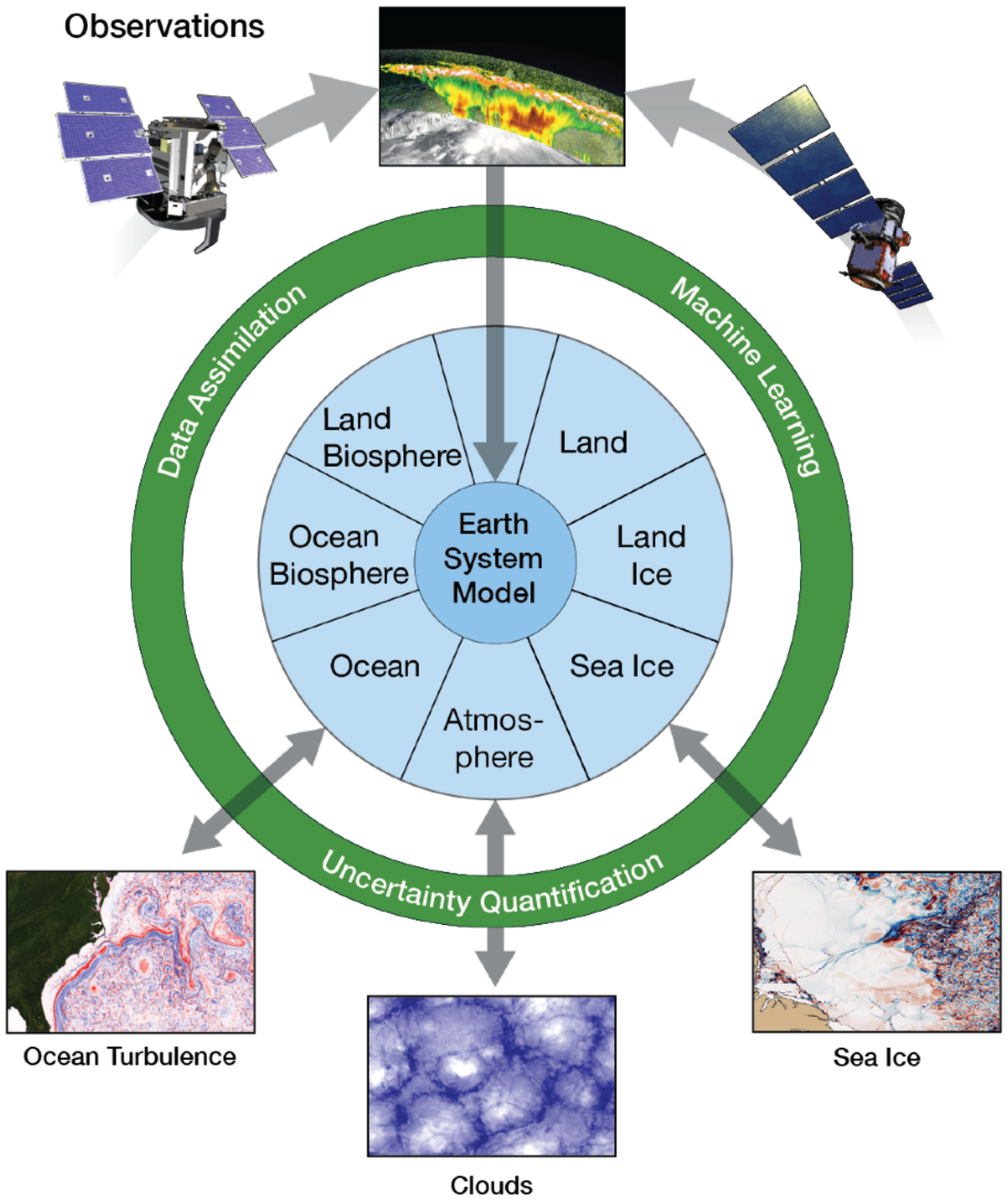


CliMA's approach to Earth system modeling

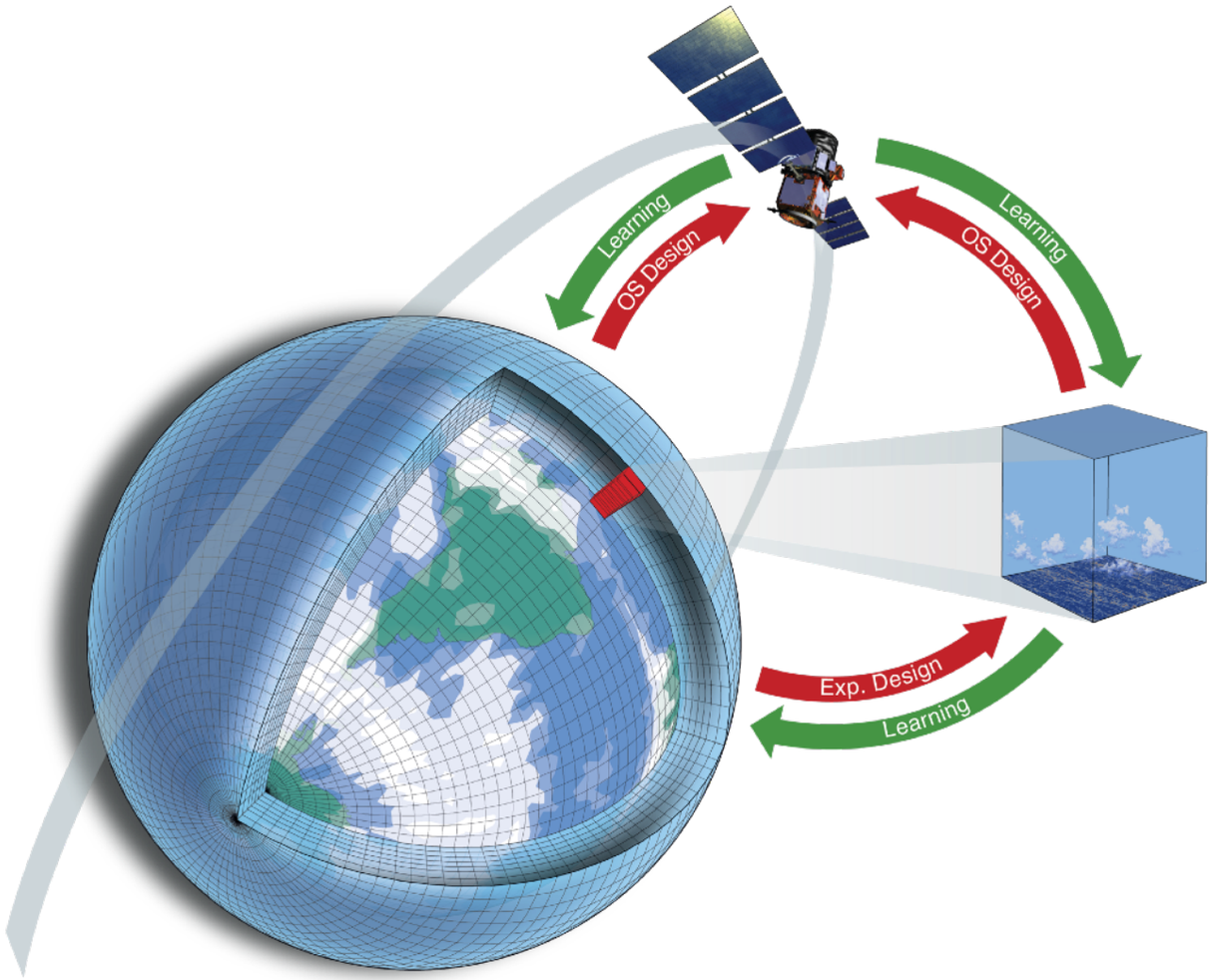
Tapio Schneider

We use a whole-Earth approach with the goal of enabling data-driven decision making in response to climate change



- *"The climate information needs of Federal, State, Local, and Private Sector decision makers are not being fully met."* U.S. GAO (2015)
- We need more accurate predictions with quantified uncertainties
- At CliMA, we are treating the Earth system as one integrated system and exploit advances in computing and data sciences to achieve a step change in accuracy and granularity of predictions

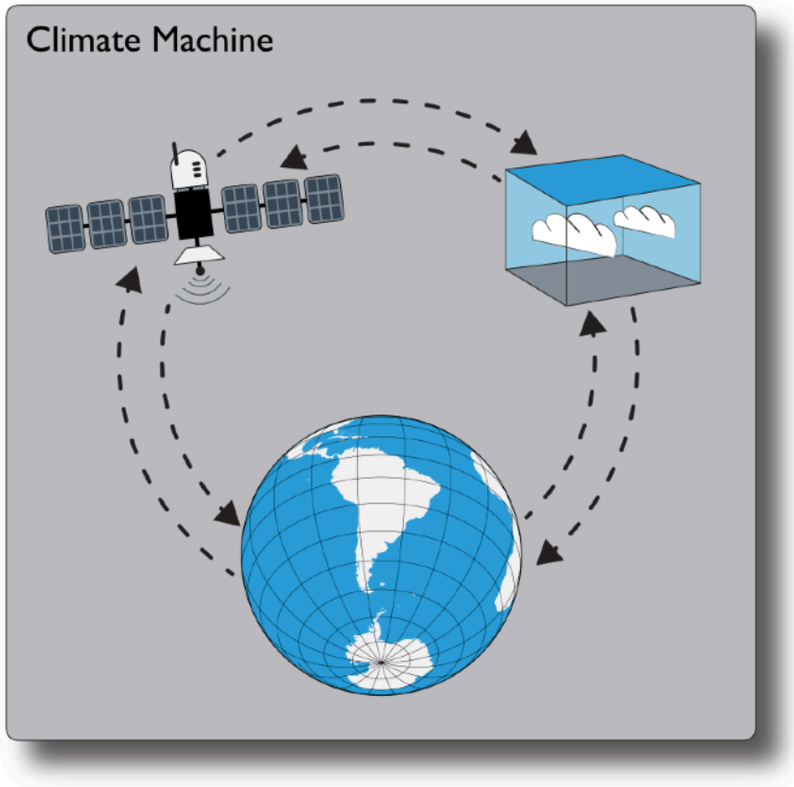
Disruptive progress from doing 10^4 times more computational experiments and using $>10^6$ times more observational data



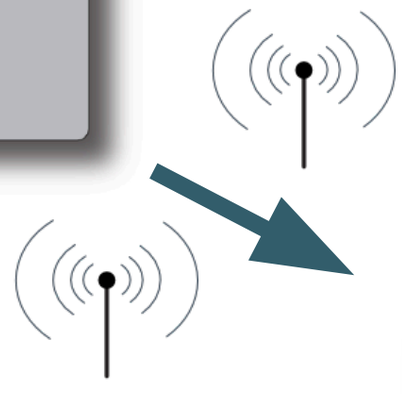
- We need to predict climate we haven't seen: use physics-based models to promote interpretability and generalizability
- Calibration and uncertainty quantification of models typically requires 10^5 runs, which is impossible for climate models
- Combining algorithms used in weather forecasting with machine learning tools for emulation, we achieved 1,000x speedup with broad-purpose *calibrate-emulate-sample (CES)* algorithm (Cleary et al. 2021)
- Demonstrated first successful simulation of Earth's cloud regimes in one model (Cohen et al. 2020, Lopez-Gomez et al. 2020)

More examples of other "Automated Research Workflows for Accelerated Discovery" in upcoming NAS report

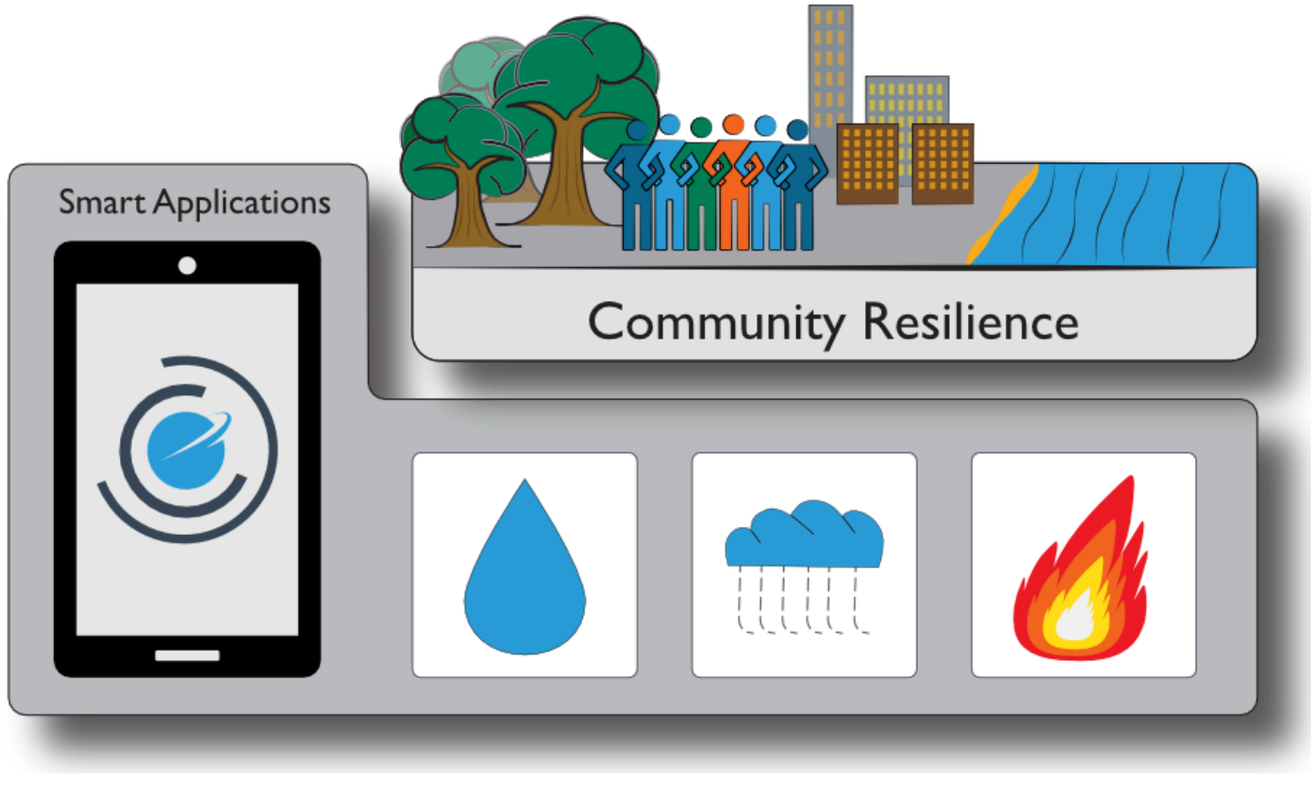
CliMA's mission is to provide a scalable end-to-end platform to provide actionable climate information



- Model continuously learns from observational and computationally generated data
- Can produce fine-grained climate information on demand, where needed for model calibration or impact assessments



- Model will anchor ecosystem of apps for detailed predictions of flood risks, risks of extreme heat, crop yields, and other impacts
- Actionable information to facilitate resiliency throughout public and private sectors



This is open science and team science that bright young scientists gravitate toward

Postdoc (statistics)

Postdoc
(engineering)

PhD student
(applied math)

PhD student/postdoc
(atmosphere dynamics)

Software engineer

Postdoc
(CFD)

Postdoc
(atmosphere)

Data scientist
(industry experience)

Research scientist
(atmosphere)

CliMA's approach and scaling challenges

Approach

- Combining new theory (e.g., coarse-graining approaches), advances in computing (e.g., distributed high-resolution simulations of clouds) and learning from observational data has the potential to lead to breakthroughs in Earth system modeling
- Computational and development effort is invested in *joint* calibration and uncertainty quantification of Earth system model components
- It results in models that at once are good predictive tools *and* tools for scientific investigation (they can be run efficiently after calibration and UQ)

Scaling challenges

- Workforce: Approach requires closely integrated teams with diverse expertise, which ideally capitalizes on the energy and enthusiasm of early-career scientists for such work (well suited for universities)
- Funding: Sustainable federal funding for larger-scale team science is currently unavailable outside government labs (and private funding is not sustainable)
- Scientific career incentives: Career incentives favor single- or few-PI projects; papers as primary products narrow perspective and divert from a focus on societally relevant impacts