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A Paradigm for Digital Twins to Safeguard the Planet

Big Idea. Develop a multi-fidelity, scalable, long-lived open-source platform which consists of protocols, such as quantification and analysis of dynamic uncertainty, that enables systematic analysis of Earth system processes. From this platform, scientists will be able to build problem-specific digital twins. The problem-specific digital twins would continuously adapt as new data is ingested; detect changes in the climate system; measure response to climate mitigation actions; integrate scientific understanding; inform policy decisions; and reduce risk by being uncertainty-aware.

Reasoning and Justification. Other open-source and "Digital Twin" initiatives are underway both within the US and outside. By using the latest developments in mathematics, statistics and computing, the US can supersede existing efforts by providing a systematic approach to continuous-adaptation and uncertainty quantification. Uncertainty-aware Digital Twins invert observed time-lapse data for the system's state using established techniques from simulation-based inference; differ from existing approaches by enabling systematic analysis of Earth system processes and include analysis of dynamic uncertainty; and update themselves as new data comes in, using current state to make predictions of future states according to different scenarios.

Requirements. The research collaboration and infrastructure needed to develop the platform for problem-specific digital twins on Earth system processes consist of:

- Interdisciplinary collaboration between mathematical modelers, biological, physical, chemical, social science domain experts, and software engineers
- contemporary open science practices such as adoption of FAIR (Findable, Accessible, Interoperable, and Reusable) guiding data principles and adoption of standards working with organizations e.g. Open Geospatial Consortium (OGC) and the Earth Science Information Partners (ESIP).
- Access to massive computational infrastructure (computer and storage)
- Long-term sustained investment in software and software maintenance

Value and Impact. The value and impact include the following and more:

- Mathematical and statistical methods to enable continuous adaptation for problem-specific dynamical systems
- Detect "change/tipping points" including social and ecological responses to climate mitigation measures
- Make policy decisions to start or optimize climate mitigating measures along with confidence levels
- Inter/multi/cross-disciplinary long-term effort spanning many disciplines
- Prototype model for global cooperation between the U.S. and other countries
- Potential for generating huge amounts of data for education and experimentation purposes while training the next generation workforce

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