LOI for AWS Impact Computing Project

Shifting Climates: A Simulation Tool for Leveraging Local Interventions to Impact Global Climate Dynamics

Section 1: Contact Information

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1.9. **Lab** (if applicable): N/A
1.10. **Do you have a co-investigator** (name and contact info): No
1.11. **Other personnel** (name, title, Harvard school or external organization, and contact info):

- Project partner: The Visualization Research and Teaching Laboratory, The Department of Earth & Planetary Sciences and the Structural Geology & Earth Resources Group
- Special Consultant: Rui A. P. Perdigão: Chair Professor in Physics of Complex Systems and Climate Dynamics, Head of Meteoceanics Institute and of Synergistic Manifolds. Expert in physics-based dynamic systems and coevolutionary complexity, including Climate and broader Earth system dynamics. Contact: perdigao@meteoceanics.org

1. **Section 2: Proposal Information**
   1.1. **Title of Proposal:** Shifting Climates: An Advanced Simulation Tool for Leveraging Local Terraforming to Impact Global Climate Dynamics
   1.2. **What is the term length of the proposed project (up to 2 years)?**
   18 months
   1.3. **Please select the area of study (select all that apply):**
   Climate Change
   1.4. **Total direct costs requested (up to $380,000):**
   $380,000
   1.5. **Project abstract (limited to 250 words):**

Climate change demands innovative thinking beyond disciplinary boundaries. Emerging research in climate studies has recently noted 'hotspots'—regions in which climate changes manifest with heightened intensity. Concurrently, advancements in earth sciences, physics present new methodologies for interpreting and influencing climate patterns through complex systems dynamics. In parallel, the field of Landscape Architecture assumes stewardship for adapting landscapes for increased performance and resilience. The project proposes to combine these fields by creating a global climate simulation tool that would allow to investigate the potential of targeted terraforming interventions at critical global hotspots. The tool will integrate geospatial, atmospheric, and climate data, enabling us to test the potential of leveraging interventions in climate hotspots to influence and alter the global

climate system. If successful, the tool will present a new means for climate action beyond *mitigation*—policy measures for controlling future worsening of climate dynamics—and *adaptation*, increasing landscape resilience by introducing the concept of *shifting* climates -- modulating the landscape locally to affect global climate dynamics. This effect is already applied on a local level, for example, for combating urban heat islands, and has immense global potential. The simulator will test how decentralized and parallel strategic terraforming, foresting and planting might affect broader climate dynamics and enhance global climate resilience. It will yield actionable, localized strategies that hold the potential to catalyze global environmental impacts. While too large in scope for a single institution to develop, the proposed simulator can provide a platform for prototyping and coordinating global climate action.

2. Section 3: Research Project Description

State the problem you are investigating. Include key questions that need to be answered and their significance. (limited to 250 words):

Climate change is one of the most pressing challenges we face globally. Despite the interrelations between different parts of the globe, there remains a challenge in devising a coordinated approach. Beyond mitigation efforts aimed at preventing further deterioration, geoengineering efforts are only conducted in more developed areas, raising criticism about the environmental injustice they perpetuate. However, leveraging targeted interventions such as terraforming, foresting, and planting in hotspots for the benefit of the entire system has not yet been explored.

Scientific advancements in complex system dynamics indicate that local actions, when performed at certain hotspots, may alter the larger climate system's dynamics. The project aims to investigate, simulate, and determine which forms and scales of targeted interventions in climate "hotspots" could influence global climate systems and whether that influence could indeed be leveraged to shift global climate dynamics. Key questions include: (1) Mapping and identifying critical hotspots; (2) Exploring potential types and scales of adaptation actions that produce notable effects; (3) Studying the nature of decentralized actions' impacts (e.g., how many hotspots need to be activated to affect a system? Does activation need to be concurrent or sequential?); (4) Exploring different strategies for shifting climates and assessing the ability to conduct strategic intervention on the climate system. These would be performed by combining geospatial, 3D, and atmospheric datasets and conducting physics-based simulations using the proposed tool.

2.1. **State the overall goal of the research** (limited to 250 words):

The goal is to develop a prototype for a climate simulation model, which would allow the design and simulation of the effects of local interventions at climate hotspots on global climate system dynamics. This prototype is designed to enable testing different spatial strategies and their combinations in light of their impact on local and global climate resilience. These, in turn, can generate actionable insights and guide strategic planning for climate resilience across the globe. In contrast to current attempts at mitigation, or mapping-based coordination of actions, the project will allow testing of actual terraforming, foresting, and planting strategies, indicating the ways and degrees to which they affect the system. This would allow devising recommendations for policy and design as well as dedicated planning for hotspots as a non-contiguous system of leverage nodes for influencing global climate resilience. As such, the project is a high-risk, high-reward effort—if it succeeds, it could potentially equip us with measures to shift and influence certain effects of climate change. If it fails, the way we structure our research will allow us to learn about simulation limitations when dealing with complex climate systems at the planetary scale.

Does this represent a new direction, or does it build on existing work?
This is a new direction of research. The work is enabled due to recent advancement in earth science physics and complex system dynamics. In this context, research on Climate System Dynamics has identified the presence of coevolutionary system -- a complex framework that involves interacting processes evolving together across different time and space scales. These systems are intricately linked and influence each other, affecting the way climate systems are understood. This allows us to view the climate system as a bi-directional system operating with data-driven and process-based system dynamics, a system that is both influencing and can be intervened it. This interdisciplinary framework opens a possibility to design a platform to prototype and test landscape adaptation that responds to climate systems, and at the same time assess the effect of the adaptation on the climate system. In this approach, landscapes susceptible to climate risk in global hotspots, become computational units through their adaptation, potentially enabling a local solution to benefit the global system. This theory has not yet been explored or tested in landscape architecture or climate research.

See: Perdigão, Rui AP. "Complexity and sustainability: from system dynamics to coevolutionary spacetimes." *Introduction to Designing Environments: Paradigms & Approaches*. Cham: Springer International Publishing, 2023. 11-32. https://doi.org/10.1007/978-3-031-34378-0_2

What is the tangible output/artifact you anticipate coming from your research? (limited to 250 words):
The goal is to prototype a global climate simulator which will combine complex systems dynamics with geospatial and atmospheric data and allow to test landscape-based interventions and simulate their effect on larger scales. The tool will allow to input adapted ground/vegetation conditions to the system in the specific location, examine the before/after performance of the local climate, and understand the impact on the global system dynamics. It will allow to test the scale and nature of effective climate shifting actions, examine the potential of concurrent or sequential actions in different hotspots, and assess the need for employing an adaptive landscape tuning for enhancing the performance. The requested funds are indented to build a dedicated team and accompany it with ongoing scientific support toward the development of the tool.

2.2. **Elaborate on the use of advanced computational technology, methodology, and data architectures that will play a role in accomplishing this project (limited to 250 words):**

While specific GPU and computational technology capacities are to be defined, the project is anticipated to involve the following aspects: (1) High-performance computing to handle complex climate simulations; (2) Data integration for linking geospatial and atmospheric datasets from global monitoring sources (3) Advanced simulation models for conducting high-resolution climate modeling to explore the interactions between local interventions and global climate dynamics; (4) Systems-of-Systems Framework: developing a integrated approach that links local systems (hotspots) with global models, supporting scalable analysis and intervention testing; (5) Visualization and user interaction both for visualization of simulation outcomes and for user- interfaces purposes to allow scenario testing and stakeholder collaboration; (6) Data Management and storage to ensure efficient access and security for simulation outputs, alongside automated data validation measures.

Describe your computational needs/resources, including compute power and/or storage capacity (limited to 250 words):

In terms of personnel, we estimate that we will require full time engineer/programmer for 6–12-month period with expertise in physics. In addition, given the project's exploratory nature, we will require a couple postdoctoral researchers to support both early-stage exploration and modeling.

In terms of computational resources, we envision a few phases/needs:

a) **Low order model design and visualization (Harvard Visualization Lab):** By integrating physics engines and visualization rendering with geospatial data, the lab currently supports visualizations of wildfire and flood scenarios. The project envisions a collaboration with the viz lab for visualizing and calculating the modulations of the local environments and their effect on the local scale in a low-order model.

b) **Simulator prototyping** (**Nvidia Earth-2):** The project will aim to partner and achieve collaboration and/or support from NVIDIA for conducting the planetary scale simulations requiring multiple atmospheric data sets with their recently launched AI tool Earth-2, designed as a high-resolution planetary climate and weather simulation platform. We hope that this tool would be made available for running some of the simulations involving atmospheric-related data sets to compute the complex system dynamics. However, there may be a need for using Amazon computing resources for this task should this avenue not be available.

c) **Simulator Deployment** (**Amazon Computing)**: The project aims to use Amazon computing power and storage for hosting and running the developed simulator and supporting user access and simulation on it.

2.3. **Identify the six-, twelve- and eighteen-month milestones towards creating the identified artifact** (limited to 250 words):

- **Six months**:
    a) Activity: Data collection, landscape adaption design – preliminary, mapping hotspot identification, preliminary model development, consultation with experts.
    b) Milestones: Data collection, hotspot mapping
- **Twelve months:**

a) Activity: Model construction and initial simulations, UI for accessing the tool, advanced scenario development and modeling, tool refinement, landscape adaption design – advanced, consultation with experts.
b) Milestones: Initial simulations, prototype UI

- **Eighteen months:**
  a) Activity: Advanced simulations of adaptation scenarios, landscape adaption design – advanced iteration, consultation with experts, preparation for Dissemination, presentation to stakeholders and dissemination.
  b) Milestones: Prototype simulation tool, publication

3. Section 4: Data Science/Computing/Social Impact

3.1. Describe key stakeholders/beneficiaries (e.g., agencies (public or private), government, non-governmental organizations, foundations, policymakers, etc.) that you envision to play key roles in facilitating the impact of your research (limited to 250 words):

For the first prototype, the anticipated beneficiaries include governmental agencies, NGOs, policy organizations, and academic research institutions focused on climate change and climate resilience. We aim to deliver an actionable decision-support model to aid policymaking and planning for sustainable environmental systems. Such a tool is needed to bridge the gap between local intervention and global climate action. Developing such a tool may require resources that exceed the capacity of a single organization, highlighting the need for collaborative efforts to bridge the gap between emerging research and climate action. These stakeholders would be able to leverage the platform for more informed decision-making and strategic planning, as well as for developing and testing global actions as a basis for policy, planning, and design. We also anticipate the model initiating a process of targeted planning for the global hotspots to leverage them for global climate resilience. The tool may also lead to the formation of new stakeholder groups previously not organized yet bound by the physics of climate change, and encourage them to begin working together on climate actions.

How will this output impact/inform people and/or set the stage for ultimately leading to real world meaningful impact, i.e., how will people or communities use this artifact? (limited to 250 words)

The simulator is envisioned as an open, global climate-shifting design and planning resource. We anticipate that it can lead to new insights on potential ways for globally coordinated and adaptive climate mitigation. The tool will be developed in collaboration with the Visualization Research & Teaching Laboratory. The lab was designed to meet the challenge of visualizing complex data in Earth Science research and education and has developed many interfaces allowing interactive public engagement with the data withing and beyond the laboratory walls. While such accessibility may require additional efforts in user interface and interactive features, we aim for the same visualization capacities to allow the tool to be accessed in community meetings, city halls, or global summits. In parallel, the tool will serve the wider research community. We envision other users developing machine learning and AI protocols for testing different actions and their potential effects using the tool, augmenting our knowledge about shifting climates and leading to a quicker path for designing resilience at global scales.