**Overview**

While observatory-based Critical Zone (CZ) research produces important findings on catchment-scale processes, the global scale of disturbance in the Anthropocene typically transcend the bounds of a single site, posing a challenge for traditional investigative approaches. This scaling mismatch significantly limits the predictive power of individual site studies in the context of regional- to continental-scale environmental change. In order to advance network-scale syntheses and integrate across scales, we propose an iterative “pattern to process” and “process to pattern” approach to investigate how CZ structure controls water, carbon, nutrients, and response to overlapping disturbances in the context of multi-dimensional resilience. For this we will (1) compile existing ecohydrological data from across the continental U.S. into a multi-dimensional CZ database, (2) perform advanced statistical analysis with complex-systems tools on big data to identify state changes in ecological function and ecosystem services, (3) refine hypotheses based on these data-driven approaches, and (4) perform in-depth process investigations at three high-vulnerability focal sites in the northeast (NE) and southwest (SW). We will extract patterns, seek emergent phenomena, and identify key drivers of resilience from high-spatial-resolution observations at the continental and regional scale (e.g., CZO, LTER, NEON), and merge findings from statistical and mechanistic models at observatory scales to generate new understanding of ecosystem function and multi-dimensional resilience in the Anthropocene. Our database and complex-systems approaches will be shared to empower the CZ community to transition into a phase of data-driven hypothesis generation and cross-site research. To further enhance the growth of CZ and data science, we will implement a comprehensive education program that will educate 7-12 grade teachers and develop equitable and transformative exchange between our institutions and historically black colleges and universities (HBCUs) for undergraduate education.

**Intellectual merit**

1. We will develop an iterative, hybrid investigative framework, employing data-driven tools for identification of patterns across regional to continental scales, which can inform hypotheses for process-based modeling at the site scale and vice versa. The proposed combination of statistical and mechanistic models will bridge scales varying more than 6 orders of magnitude.
2. By using data from multiple observatories and monitoring networks and applying complex-systems tools to harness the power of big data, we will identify individual and interactive controls on ecosystem response to disturbance. This work will be transformative in its integration of statistical and process-based approaches to bridge scales and biomes. Such an approach will reduce potential bias from extrapolation of observatory-scale results to the broader CZ network and will result in a more comprehensive understanding of the CZ structure and function in the context of multi-dimensional resilience.

**Broader Impact**

To broaden the participation of underrepresented groups in CZ and data science, we will recruit, educate and empower a diverse new generation of STEM thinkers from middle and high school to the graduate college level. Our grade 7-12 education program will reach hundreds of students from high-need Vermont schools (historically-marginalized economic, racial or disability groupings) by “educating the educators” in CZ and data science. Furthermore, we will collaborate with HBCUs to offer outdoor education in Vermont for a diverse group of undergraduate students recruited from these institutions. To broaden participation further, we have included travel support for participants from the CZ network and the broader community to join, learn and build upon our approaches to continue and grow more programming across the US.

Our database will be open to the broader community and will contain data that go beyond the scope of our cluster and can be applied to generate and test more hypotheses (e.g. weathering patterns or contaminant dynamics). To learn how to address regional and global problems with complex-systems tools, we will support new participants via travel to meetings, via webinars, presentations and outreach. Furthermore, we will provide training in complex systems and the use of investigative approaches (field, lab, statistical and mechanistic modeling) for multiple undergraduate and graduate students.