**C**limate Change **H**azards in **A**ppalachia: Towards **R**esilience and **G**eoscience **E**quity in Kentucky (**CHARGE**)

1. **Overview**

Kentucky faces mounting threats from climate change and climate-related natural hazards. Extreme weather (severe thunderstorms, tornadoes, and ice storms), floods, landslides, and droughts place the state’s citizenry and economy in danger. Kentucky’s economy relies on open supply chains, predictable, safe, and high-quality food and water supplies, and community-level climate preparedness that safeguards human health and infrastructure. At present, Kentucky is highly vulnerable and lacks resilience to climate change, with impoverished, underserved, and isolated rural communities at particularly high-risk of losses from climate-related disasters. For example, historic storms in 2021 and 2022 ravaged eastern Kentucky, making global news accompanied by shocking images of Kentucky River flood waters devastating large parts of Appalachia, killing scores of people, cutting power lines, and destroying roads, railways, businesses, and homes. Another startling climate catastrophe impacting Kentucky was the long-tracked EF4 tornado that leveled parts of western Kentucky, killing 80 people, and causing >$3.5 billion in damage. Still other instances of climate change, including severe droughts, threaten to undermine agriculture and freshwater quality/availability. Changing climate dynamics not only affects the state’s economic vibrancy provided by tourism reliant on water resources (e.g., thoroughbred horse racing, bourbon distilling), but also interstate commerce facilitated by the Mississippi, Ohio, and Kentucky Rivers. The recent environmental changes in Kentucky highlight the threats posed by climate-change and associated disasters and underscores the need for extensive research to (a) understand the hydroclimatic controls that drive these events using both empirical geoscience and hydroclimate modeling techniques, and (b) develop engineering and artificial intelligence solutions that will protect the built environment and geoheritage from climate-related hazards and improve decision making. In short, safeguarding Kentucky’s communities and economy relies on building climate change preparedness and resiliency — this is the chief goal of CHARGE through geoscientific and engineering research, education, and outreach. This mission directly aligns with homeland security interests and national defense planning for the 21st century.

The United Nations Inter-Governmental Panel on Climate Change (IPCC) has indicated that anthropogenic emissions have continued to rise for all greenhouse gases (CO2, CH4, NOx) since 2010. Further, the most recent IPCC assessment states with high confidence that human activities are estimated to have caused ~1.0°C of global warming above pre-industrial levels, and global warming is likely to reach ~1.5°C between 2030 and 2052 if it continues to increase at the current rate. Kentucky has yet to experience the overall warming of other regions around the world, but the National Climate Assessment provides a snapshot of Kentucky’s climate future with continued global warming and higher emissions scenarios. The best available models suggest that Kentucky faces the potential of (a) historically unprecedented temperatures, (b) higher heat wave intensity, (c) greater variability in precipitation, (d) more extreme precipitation events, and (e) greater droughts as rising temperatures affect evapotranspiration. The implications of these changes are poorly understood across most domains, including economic development and public health. For example, studies scaled to directly assess the state’s water budget and potential threats to water resources under the influence of higher temperatures or more variable precipitation have not been undertaken. The CHARGE project provides a unique opportunity to assess the availability and quality of surface waters in Kentucky, and model potential changes to the water supply under different scenarios of climate change, for example using the range of estimates (i.e., the Shared Socioeconomic Pathways) produced by the IPCC report. The outcomes will have considerable implications for Kentucky’s tourism and trade and will inform the development of more resilient and sustainable economic development practices. The outcomes also place physical constraints on the potential for climate-driven hazards such as flooding and landslides. Understanding and forecasting climate change from a physical science basis is not enough; CHARGE seeks to apply that knowledge to improve the resilience of our infrastructure and industries and adapt Kentucky to the conditions of a changing planet through close collaboration with the engineering disciplines, particularly those that intersect with the Earth sciences through civil, environmental, materials science, and artificial intelligence applications. As commerce and transportation networks transition toward greater reliance on smart- and autonomous-vehicle technology, so too must design and structural engineering consider the range of environmental conditions of the Anthropocene (e.g., unusual, or extreme precipitation patterns, wind speeds, plant phenology, etc.) that may disrupt supply chains and connectivity among the internet-of-things. In other words, considerations of climate change are critically important for the future of commerce in Kentucky, and project CHARGE will take steps towards addressing these needs through research and human capital expansion.

Although significant expertise exists within the Commonwealth, to date no harmonized research effort towards understanding climate change has been undertaken by the state’s institutes of higher education, which unfortunately provide few answers and little relief when climate disasters strike. Indeed, climate science and climate-related hazards engineering research are poised for growth in Kentucky universities and can become more competitive with peer institutions for major research awards. Numerous transdisciplinary opportunities exist within the National Science Foundation (NSF) to fund climate change science, sustainability, and engineering research: Critical Aspects of Sustainability, Frontiers in Earth Science, Signals in the Soils, Geo-informatics, CAREER, Human-Environment-Geographic Sciences, Major Research Instrumentation, Hydrological Sciences, Geomorphology and Land Use Dynamics, Sedimentary Geology and Paleobiology, Paleo Perspectives on Present and Projected Climate, Engineering for Civil Infrastructure (Natural Hazards Engineering Research Infrastructure) and Operations and Design (Humans, Disasters, and the Built Environment), and Disaster Resilience Research grants. The CHARGE project can make a compelling argument to the EPSCoR Track 1 program around the need for new climate change facilities and research expertise centered in Kentucky. Several CHARGE co-PIs have had program-level funding from NSF in the past decade and will serve as mentors and senior collaborators to new faculty for proposal development. Discussions with program managers suggest a strong appetite for proposals related to climate change in Appalachia, given the clear connection to science in the public interest, and the potential implications and broader outcomes for environmental justice.

1. **How does CHARGE Connect to FY2022 NSF Funding Priorities?**

The CHARGE project makes direct linkages to FY 2022 funding priorities at the NSF (bullet points below, in bold) related to advancing the frontiers of research into the future, ensuring accessibility and inclusion, and securing global leadership at the frontiers of science and technology. In particular, the CHARGE PIs envision an EPSCoR Track I proposal that improves research competitiveness in the geoscience (EAR/GEO) and engineering (ENG) directorates and will lead to a hierarchy of transdisciplinary and program-level NSF proposals with special emphasis on science and engineering to improve the resilience of Kentucky’s people, businesses, supply chain, and infrastructure to climate change. The development of detailed climate and water data will afford additional opportunities for university researchers to engage businesses in the Commonwealth reliant on water resources to sustain their operations, and improve decision making by the policy, emergency management, disaster response, and public health communities.

**• Advances in Climate Science and Sustainability Research:** CHARGE seeks to build faculty with cutting-edge expertise on climate change, climate-related natural hazards/disasters, and building resilience through science and engineering at the state’s universities, including improving existing facilities and adding new infrastructure to support a more competitive research enterprise in Earth and environmental science and allied engineering disciplines (civil, environmental, industrial, electrical, materials science and computer science). Climate change research is the natural domain of Earth scientists, yet geological perspectives on climate variability and Kentucky’s climatic future are understudied. Numerous natural archives of climate processes and environmental change exist in the state’s sediments, soils, caves, natural waters, and old-growth trees, yet these records have never been thoroughly studied from the perspective of climate change. In addition, historical and heritage documentation (chiefly family, church, public, and military records) of climate change and human impacts has neither been fully compiled nor analyzed statistically or with machine learning to assess spatiotemporal trends; such data will refine our understanding of the mean and extreme states of Kentucky’s climate and provides a natural linkage to colleagues in the social sciences and humanities. Harnessing the power of expanded (centuries to millennia long) records of climate change has allowed states like California to plan for environmental emergencies and design public policies to help safeguard human life and property; this approach could benefit policy makers in Frankfort as well as first responders across the state. Similarly, opportunities exist to develop engineering solutions to climate-related hazards like flooding and landslides, through improvements to infrastructure (e.g., river port facilities, dams, bridges, roadways, railways, etc.), slope stability measures, and water treatment processes to combat warming-related processes of eutrophication (harmful algal blooms). Opportunities also exist to develop innovative sustainable building materials (e.g., net carbon-neutral materials, recycled materials, biomaterials, etc.) and sustainable construction practices. (e.g., integrated waste management, adaptive reuse, additive construction, etc.) to facilitate climate-resilient communities.

New faculty hires in climate science, climate modeling, surface water hydrogeology, geoinformatics, geohealth, surface processes, geophysics, geomicrobiology, engineering geology, civil engineering, environmental engineering, computer science, materials science and artificial intelligence with cutting edge research and computational laboratories will collaborate to pursue NSF funding with the explicit aim of understanding climate in Kentucky across spatiotemporal scales, elucidating the controls on climate-related hazards (landslides, floods, droughts, severe storms), and engineering new solutions to bolster resilience and promote sustainable communities and business solutions. This objective links to our basic goal of enhancing fundamental research and development in geosciences and engineering.

• **Advances in Equity in Science and Engineering**: CHARGE aims to address shortcomings in Earth and environmental science and engineering faculty equity, diversity, and representation, as well as improve the culture of the disciplines with respect to belonging, accessibility, and inclusion. Statistical analyses of faculty demographics are clear: the Earth and environmental sciences rank last in racial and gender diversity compared to all other STEM fields in our nation’s universities, these same demographics hold true for engineering faculty as well, and Kentucky is no exception. The growth of faculties across the state through the CHARGE project provides one of the best opportunities for Kentucky to improve the diversity of its Earth and environmental science and engineering faculty. The CHARGE proposal can make a compelling case that nascent efforts to improve graduate student diversity, for example through UK and WKU membership in the American Geophysical Union’s Bridge Program (designed to produce new African American, Hispanic American, and Native American Ph.D. graduates in earth, atmospheric, and environmental sciences), will be strengthened through the addition of diverse principal investigators leading research programs that address the impacts of climate change on some of Kentucky’s most underserved minority communities. The CHARGE proposal will build on initial efforts to establish pipelines among Historically Black Colleges and Universities (e.g., Kentucky State University), community colleges, and the major research universities, allowing for more seamless transfer and training of students from under-represented groups in Earth and environmental science and engineering.

• **Advancing the Frontiers of Science and Engineering**: CHARGE aims to expand cutting edge, fundamental research, and development of artificial intelligence (AI) with special emphasis on the intersection of machine/ deep learning and climate change for improved modeling, risk detection, decision making, and sustainable economic development. Opportunities exist to improve regional climate and earth systems models and seasonal water budgeting through AI-facilitated supervised learning, big data mining, time series analysis, geospatial and spatiotemporal data integration and analysis. Extreme hydrological event classification under global climate change, facilitated through machine learning, holds significant promise for disaster prediction, management and relief and therefore building resilient communities.

**Research Pillars**

1. **The Science of Climate Change in Kentucky**

CHARGE seeks to address the knowledge gap associated with mean and extreme states of Kentucky’s climate and water cycle, and their collective vulnerabilities to global warming. Earth and environmental scientists will analyze Earth’s natural archives (e.g., sediments, soils, cave deposits, surface and ground waters, tree rings) and remote sensor data (satellite, drone, and shallow geophysical measurements of atmospheric processes, land cover, plant life, rocks/sediments, and inland waters), as well as build computational models and cyberinfrastructure to track environmental variability and the hydroclimate history of Appalachia. The main objective is to expand the climate change archives of Kentucky from their current state (<200 years) to ~10,000 years using geological and atmospheric datasets and applying those data to construct more accurate predictive models of regional hydroclimate. These data naturally connect to the geohealth of Kentucky’s people, supply chain and infrastructure resilience, and decision-making grounded data-driven analytics. In parallel with increasing climate science knowledge in Kentucky, CHARGE will develop new and forward-thinking process-based quantitative models to predict Kentucky’s landscape and ecosystem responses to climate change through the remainder of this century and beyond. This will include developing innovative linkages between the physics-based geomechanical and landscape evolution models with the impacts of seasonally increasing temperatures, precipitation, and evapotranspiration, variability in forest and soil health, and dynamics of sedimentation and erosion influenced by warming. Novel geological, geophysical, and geochemical, and/or DNA technologies to assess landscape evolution and the water supply during periods of climate stress will be pursued. CHARGE new hires will be recruited from diverse backgrounds (race, ethnicity, gender) to improve representation across the faculties of the state’s universities. CHARGE seeks to expand existing frameworks (e.g., NSF-sponsored Unlearning Racism in Geoscience, AGU-Bridge, etc.) and develop new initiatives to effectively support the development and maintenance of these faculty as they onboard to our campuses. Expanding evolving distant-learning opportunities with high-schools will further human talent development. The mission will also take advantage of humanities and Minorities in Agriculture, Natural Resources and Related Sciences expertise to initiate a geoscience and engineering focused dialog with Kentucky’s citizenry to manage and protect our rich environment, as well as the health and well-being of its people more justly.

1. **Climate Change Hazards and Disaster Engineering in Kentucky**

CHARGE seeks to improve upon climate preparedness and community resilience through engineering-focused studies on natural hazards connected to water availability, water quality, and warming temperatures or extreme weather patterns. Engagement by CHARGE engineers will involve the development of innovative, quantitative, life-cycle solutions to improve the readiness and resilience of Kentucky’s built environment, as well as safeguards on economic assets. Landslides, floods and droughts present complex threats to traditional supply chain and transportation networks (road-, rail-, air-, and waterways) that facilitate commerce throughout the state, and amplification of temperature, precipitation, and wind regimes will require the engineering of new sustainable and resilient materials and infrastructure systems to operate in evolving environmental conditions. Geohazards such as landslides, rockslides, and debris flows continue to pose significant challenges to the state’s rural and mountainous eastern region, and amplification of the hydrological cycle predicted by the National Climate Assessment suggests that the size and frequency of mass wasting events (i.e., slope failures) may increase as climate warms and vegetation composition and density changes in the coming decades, threatening human life and infrastructure. Instrumented hillslopes and long-term monitoring studies that aid in prediction and afford early warning of slope failures are strongly aligned with CHARGE priorities. In the central and western regions, changes to groundwater flow will require engineering innovations for coping with karst environments. These innovations will include development of advanced materials (e.g., self-healing concrete), adaptive infrastructure (e.g., intelligent and data-driven roadways and utilities), and enhanced environment visualization tools (e.g., augmented reality). In addition, rivers, lakes, and engineered reservoirs are susceptible to eutrophication as temperatures warm; harmful algal blooms are yet another threat that accompanies global warming in many regions, and has already been seen in nearby Ohio. Blooms of cyanobacteria or other invasive species harm water quality for both municipal and industrial users, and may constrain ecosystem services (e.g., recreational fishing, boating) that are valuable to Kentucky from the perspective of ecotourism. *In situ* chemical treatment or bioremediation may be necessary to safeguard water supplies for communities throughout the state. As with the climate science objectives, CHARGE new hires in engineering disciplines will be recruited from diverse backgrounds (race, ethnicity, gender) to improve representation across the faculties of the state’s universities.

1. **Artificial Intelligence and** **Climate Change in Kentucky**

CHARGE presents an exceptional opportunity to build-out the intersection between AI and climate change science in Kentucky, particularly through the development of enhanced sensor networks and machine/deep learning applied to “big data” for extreme hydrological event forecasting, early warning detection, and disaster prevention and management. Transient or permanent sensors arrays, used to measure hydrometeorological conditions, soil moisture, water temperature, dissolved oxygen, chlorophyll a, and other environmental parameters, can be developed and installed to track conditions in high-risk river confluence settings (e.g., Clay County, near the headwaters of the Kentucky River), as well as threatened dams and reservoirs across the state. AI can quickly discern patterns in data from large sensor networks that humans cannot. In addition, AI is dynamically intuitive, meaning that discrete changes in a few datasets can be used to make predictions across the entire network system more efficiently, leading to more informed responses to change and better policy decisions for at-risk communities. Long-term monitoring experiments, linked to the appropriate cyberinfrastructure, are envisioned to provide extensive data on the evolution of Kentucky’s waterways and catchments as climate and associated ecosystems evolve moving into the future. CHARGE new hires will fill the gap that exists between data science faculty and geoscience faculty. Thus, providing a new generation of interdisciplinary geoinformatics scientists that will position the state to become more climate resilient. CHARGE will seek to build capacity through the state’s investment in ground-based hydrological and climatological sensor networks, as well as investments in world-class cyberinfrastructure dedicated to climate change in Kentucky.