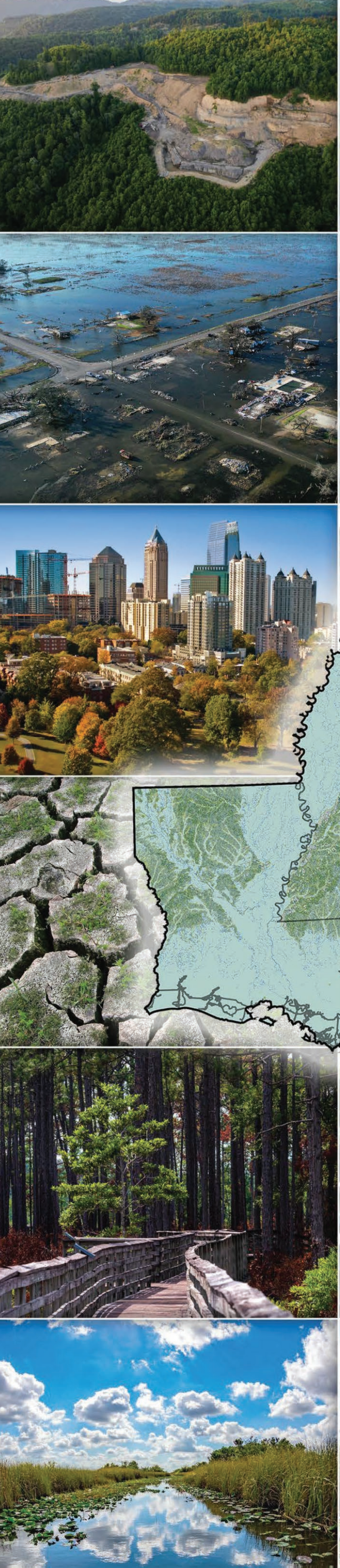
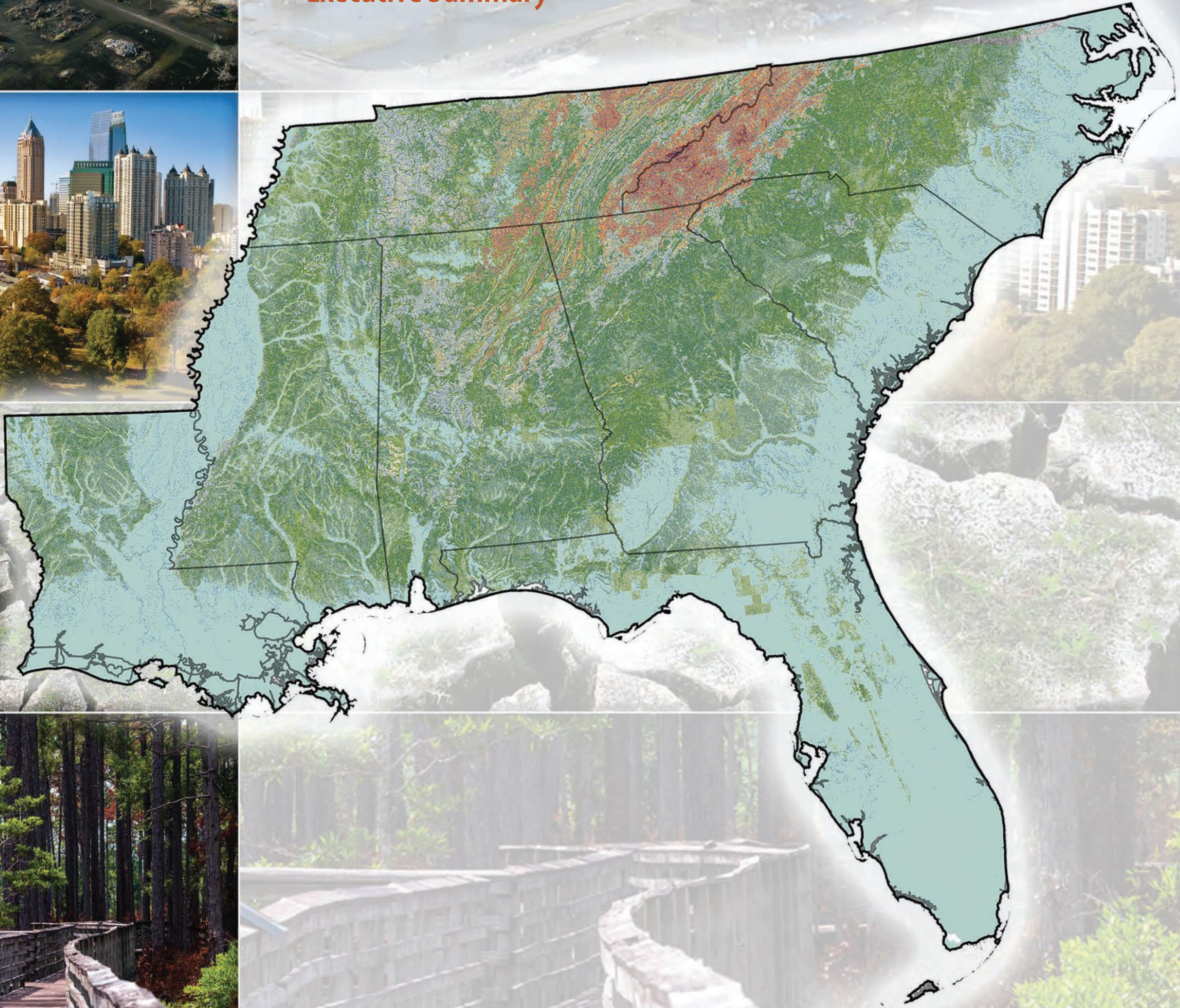
DOE/SC-0220

Optimizing DOE Opportunities to Research Land–Atmosphere Interactions in the Southeast

Workshop Report

Executive Summary





U.S. DEPARTMENT OF ENERGY | Office of Science

Biological and Environmental Research Program

Southeast Land–Atmosphere Research Opportunities
Virtual Workshop

August 23–24, 2023

Convened by
U.S. Department of Energy
Office of Science, Biological and Environmental Research Program

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About BER

The Biological and Environmental Research (BER) program advances fundamental research and scientific user facilities to support U.S. Department of Energy missions in scientific discovery and innovation, energy security, and environmental responsibility. BER seeks to understand U.S. biological, biogeochemical, and physical principles needed to predict a continuum of processes occurring across scales, from molecular and genomics-controlled mechanisms to environmental and Earth system change. BER advances understanding of how Earth's dynamic, physical, and biogeochemical systems (atmosphere, land, oceans, sea ice, and subsurface) interact and affect future Earth system and environmental change. This research improves Earth system model predictions and provides valuable information for energy and resource planning.

Cover Images

Top to bottom: (1) Aerial view of quarry in the southern Appalachian Mountains. Courtesy Adobe Stock. **(2)** Flooding from Hurricane Delta in Creole, La. Courtesy Getty Images. **(3)** Atlanta, Ga., skyline. Courtesy Getty Images. **(4)** Drought at Lake Jordan, N.C. Reprinted under a Creative Commons license (CC BY-SA 2.0 DEED) from Keith, Flickr. **(5)** Weeks Bay Pitcher Plant Bog, Baldwin County, Ala. Courtesy Adobe Stock. **(6)** Florida Everglades. Courtesy Adobe Stock**. Cover Map:** Landforms map of the Southeast land–atmosphere study area. Courtesy Chris DeRolph, Oak Ridge National Laboratory.

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Optimizing DOE Opportunities to Research Land–Atmosphere Interactions in the Southeast

Workshop Report

Executive Summary

May 2024

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Biological and Environmental Research Program

Executive Summary

The southeastern United States (Southeast), with its complex and varied environments, is an area of tremendous economic, ecological, and societal importance to the country. The region is characterized by heterogeneous landscapes (i.e., geology and soil type) and a long history of human land use coupled with a warm temperature regime and high precipitation. As a result, soil erosion and deposition are pronounced, vegetation recovery is rapid, and human modification is extensive across the region.

To better understand land–atmosphere interactions in this important and complex region, research communities supported by the U.S. Department of Energy's Biological and Environmental Research (BER) program identified the Southeast as a priority region of interest. In Summer 2024, the third Atmospheric Radiation Measurement Mobile Facility (AMF3), one of three mobile monitoring facilities designed to collect atmospheric and climate data from undersampled regions around the world, will begin operations in northwestern Alabama's Bankhead National Forest (BNF). The AMF3-BNF 5-year deployment, from 2024–2029, will monitor the effects of feedbacks among aerosols, clouds, and precipitation on plant physiology and canopy-scale fluxes. It will also focus on scale aggregation to resolve the role of local forcing on larger-scale processes.

To enable broader AMF3 involvement by the science community, the BER Environmental System Science (ESS) program organized the Southeast Land–Atmosphere Research Opportunities (SELARO) workshop in August 2023. The purpose was to identify gaps in scientific understanding of terrestrial processes in the Southeast (defined as states bounded by the Gulf of Mexico to the south, the Atlantic Ocean to east, the Mississippi River to the west, and extending through Tennessee and North Carolina to the north) and explore opportunities to use the AMF3-BNF deployment to coordinate and leverage research efforts across the region.

Many parts of the Southeast have experienced repeated anthropogenic forcings. Farming, hunting, burning, and settlement of the region by Indigenous Peoples first shaped the distribution of plant communities, which in turn influenced European colonization patterns. Timber harvesting was common during the expansion of European settlements, and production forestry continues today. Agricultural production was extensive and then waned through the 20th century, creating a period of afforestation following agricultural abandonment. Today, many formerly agricultural landscapes are undergoing rapid urbanization and suburbanization. Overlying these patterns of anthropogenic land use are frequent disturbances from hurricanes, tornadoes, wildfires, drought, flooding, ice storms, and the occasional blizzard.

An additional characteristic of the Southeast is its overall landscape complexity. Unlike the western United States, where broad expanses may share similar characteristics, Southeast topography, drainage patterns, vegetation, and development patterns vary widely across relatively small spatial scales (< 1 km). This is due to the region's underlying geology and soil development, species biodiversity patterns, and land ownership and use coupled with strong forces of erosion, weathering, and rapid plant growth in the warm, wet climate.

Emerging Themes and Challenges

The SELARO workshop sought to identify research opportunities across the Southeast region that can leverage and expand upon the AMF3-BNF deployment. The workshop was organized around the following research topics: two-way carbon, energy, and water fluxes and land–atmosphere interactions; ecology, biogeochemistry, and disturbance; and hydrology, ecohydrology, and the terrestrial–aquatic interface. Despite the diverse range of perspectives and expertise among workshop participants, discussion coalesced around similar themes and challenges:

- **Wide-ranging spatial heterogeneity scales across the landscape complicate generalization of ecosystem processes and lead to differential land–atmosphere coupling.** The Southeast is characterized by strong heterogeneity driven by topography, climate, physiography, and human land use that results in a land cover mosaic. Knowledge gaps exist in understanding how to upscale parameters, represent processes across diverse landscapes, capture uncertainties across scales from soil microtopography to entire landscapes, and characterize interactions between land cover and biological processes.

- **Climate change predictions suggest future changes in vegetation growing season and productivity.** The Southeast is expected to experience changes in temperature, growing season length, drought, and flooding, which can interact with other disturbances endemic to the region. Key challenges include improving understanding of how climate change will impact land–atmosphere interactions. Precipitation changes alter soil moisture, flooding, and drought and rising temperatures extend growing seasons, but their combined effects on primary productivity and carbon-nutrient cycles remain unknown. Soil and plant processes must be linked to the atmosphere to understand climatic drivers on ecosystems. Improvements to models to capture high-resolution spatiotemporal data for temperature and precipitation are needed to address these challenges.

- **Disturbance regimes are expected to shift.** The Southeast is subject to a wide range of disturbance events that shape the landscape and drive ecosystem responses. A need exists to understand the trajectories and transitions of ecosystems, compound disturbances, resistant or resilient responses, and impacts on turbulent and radiative fluxes, boundary layer characteristics, and carbon and nutrient cycling. Research requires long-term field experiments, comparing sites with different levels of disturbance severity, and studying sites with different disturbance histories and legacies. Understanding individual ecosystem stress responses, which are highly unique, can help determine ecological resilience and capture transitions in models.

- **Land management and land use change in the Southeast is highly dynamic.** Changes in Southeast land characteristics are influenced by the large fraction of land under private ownership, high levels of land management, and rapid urbanization. A need exists to understand historical trends and extent and to predict the direction of change in land development and use. Furthermore, establishing a baseline is imperative before predicting future effects. A research challenge is to improve understanding of how changes in ecosystem structure and composition impact evapotranspiration, soil water, biogeochemical cycles, and carbon dynamics.

- **Hydroclimatic feedbacks require a good understanding of the water budget.** Intense water cycling in the Southeast is driven by warm temperatures, long growing seasons, dense vegetation, abundant atmospheric moisture, abundant precipitation, and high rates of evapotranspiration. Understanding impacts on the water cycle from changes in atmospheric forcing, land use, and land management requires knowledge of the missing components of the water budget. These components include evapotranspiration, soil water storage, and plant response to the atmospheric environment. Evapotranspiration is difficult to capture in complex environments containing mixed-species and/or mixed-age ecosystems. The few measurements that exist for soil water storage are shallow and fail to capture the full depth of plant-accessible water as well as small-scale microtopographic effects. Shifting vegetation patterns in the Southeast, combined with increasing human demand for water resources, necessitate improved understanding of plant response to increased carbon dioxide, changes in vapor pressure deficit, and increased temperature.

- **Land–atmosphere coupling, boundary layer dynamics, and surface-aerosol interactions are highly uncertain**. Southeast boundary layer dynamics are influenced by heterogeneous canopy cover, high rates of biogenic volatile organic carbon

(BVOC) emissions, aerosol interactions, and radiation. Coupling between the land and atmosphere drives turbulence, fluxes of mass and momentum, and boundary layer characteristics. However, a major knowledge gap exists in understanding how spatial heterogeneity, canopy structure, surface layer roughness, and boundary layer height contribute to cloud and convective processes. Radiative and cloud processes are also influenced by BVOC emissions that contribute to the formation of secondary organic aerosols. Research aimed at resolving seasonal, species, and environmental influences on BVOCs is needed. Furthermore, studies should focus on BVOC contribution to aerosols and the resulting scattered and diffuse light, which will impact canopy photosynthesis, ecosystem evapotranspiration, carbon sequestration, surface heating, and precipitation patterns.

Opportunities for Scientific Advancement

Workshop participants identified several opportunities for scientists to leverage and coordinate with the AMF3-BNF deployment to further scientific advances. These include:

- **Adding supplemental observation sites and instrumentation.** Future effects should capture a variety of different land covers, topography and underlying geologic formations, and short- and long-term meteorology that can be used to (1) enhance understanding of land–atmosphere coupling and (2) provide supplemental data for validation. Needs exist for additional monitoring sites outside BNF to capture diverse elements of the Southeast and additional instrumentation within and outside BNF to complement and extend observational activities. For example, additional *in situ* ecosystem and ecohydrology measurements could be linked with atmospheric measurements, and remote sensing data could be used to address scaling issues. Additional light, radiation, and aerosol measurements within existing and deployable (e.g., AmeriFlux) tower sites could enhance understanding of land–atmosphere coupling.
- **Including hierarchical observations**. Integrated measurements of eddy covariance, radiation, and remote sensing across the soil–plant–atmosphere continuum can improve translation from individual scales to larger spatial and temporal scales. Furthermore, a variety of gauged watersheds lie within the AMF3-BNF coverage area, and opportunities to gauge smaller watersheds can help explore interactions between hydrology and ecosystem processes. Finally, observations across a gradient will help inform how processes and parameters aggregate across land cover transitions over spatial scales.
- **Co-locating existing data.** A wealth of existing data (e.g., long-term ecohydrology monitoring, AmeriFlux, Long-Term Agroecosystem Research, Long-Term Ecological Research, National Ecological Observatory Network, remote sensing) can be leveraged to enhance AMF3 data and achieve a more holistic understanding of the system and various interactions between the land and atmosphere. Several sites support long-term ecological studies that have produced data that may support the AMF3-BNF effort beyond its current footprint (e.g., Jones Ecological Center, Tall Timbers, military bases, and national laboratory facilities). Not all data are readily available, so establishing a data integrator to access existing data and potentially develop and test models will be critical.
- **Improving models and modeling frameworks.** Some of the biggest challenges in ecosystem modeling are capturing processes across multiple scales and understanding nuanced processes that drive component fluxes. The variability and stress responses that occur in complex environments with heterogeneous terrain, mixed-species and/or mixed-age vegetation, and transitional ecosystems are poorly represented by the plant functional types used in existing models. Some approaches that can strengthen understanding and predictability of ecosystem behavior and response to forcing include (1) utilizing functional traits to represent vegetation and improve species-specific responses, (2) leveraging artificial intelligence tools to simplify parameters, (3) using linked modeling frameworks to explore uncertainties that guide measurements, and (4) capturing heterogeneity and climate resilience in coupled land surface models.