**Annual Report to NC CASC**

**Administrative**

*PI:*Imtiaz Rangwala; imtiaz.rangwala@colorado.edu

*Institution:* CIRES, University of Colorado Boulder

*Names/Affiliations of Co-Is*: Daniel Schlaepfer (Northern Arizona University); John Gross (National Park Service); David Thoma (National Park Service), Catherine Gehring (Northern Arizona University); Katherine Hegewisch (University of California Merced); John Guinotte (US Fish & Wildlife Service); John Bradford (USGS NW CASC & Northern Arizona University)

*Project Title:* Detailed soil moisture projections for scenario planning and ecological drought assessment

*Agreement Number:* G24AC00105

*Date of Report:* 02/28/2025

*Period of Time Covered by Report:* 3/1/2024 - 2/28/2025

**Purpose and Objectives**

Climate change and associated altered disturbance regimes are expected to fundamentally restructure ecosystems across the globe (Nolan et al. 2018) and these impacts may be especially pronounced in the water-limited drylands that span much of the western US and comprise the bulk of federal and tribal land (Carter et al. 2020). Climate change impacts will be especially important in water-limited dryland regions where ecosystem structure, function and composition are closely linked to moisture availability and drought stress (Huenneke et al. 2002, Huang et al. 2017, Schlaepfer et al. 2017). However, quantifying ecologically relevant drought is difficult in drylands because the response of vegetation to moisture and temperature conditions is not easily explained by meteorological indices or even by simple water balance models (McColl et al. 2022). Despite this challenge, resource managers in these drylands need datasets about future drought and moisture patterns that are both ecologically relevant and encompass the variability in projected future climate conditions (Bradford et al. 2020b, Rangwala et al. 2021). This project will address some of these needs by developing and delivering quantitative 21st century projections of water balance, water availability, and ecological drought across the western U.S. We will utilize an ecosystem water balance model with a daily time step and multiple soil layers, allowing output to represent rapid changes in particular soil layers. This model also explicitly considers the influence of vegetation, including CO2 effects, and represents both soil water potential and water content, so outputs can be linked to ecologically relevant conditions and provide perspectives about ecological drought that are appropriate for 21st century projections. The data generated by this project will include a model description paper and a set of synthetic, annual-level, ecologically-relevant drought metrics (Chenoweth et al. In Revision) that can be directly integrated into more general climate vulnerability and adaptation efforts. In addition, our products will include all the detailed data (e.g. daily, multiple soil layers, many water balance components), enabling sophisticated users to examine specific conditions that they know are relevant for their ecosystems and location.

**Organization and Approach**

The first year of the project was focused on synthesizing input data and preparation of simulations according to the proposed work and reporting schedule.

We hired a senior research scientist (Daniel Schlaepfer) in April 2024 with the official start of the project to lead the project effort. We hired a postdoctoral associate (Alice Stears) in January 2024 to help lead the development of appropriate CONUS-wide vegetation characterization. We also hired a computer programmer (Nicholas Persley) first as undergraduate contractor (January – June 2024) and then as full-time assistant since July 2024 to implement sufficient input, output, and throughput capabilities of the simulation program.

We organized an advisory committee of seven members (not including the project team) from regional and national Climate Adaptation Science Centers. After an early kickoff meeting in November 2023 between the larger project team and the advisory committee, we organized two additional meetings. We discussed at a meeting in April 2024 the representation of soils in the simulations. Decisions taken included (i) to use the new NRCS digital soil map product (SOLUS100) instead the NRCS soil survey databases and (ii) to implement a representation of the effects of organic soil content on the water release curves into the simulation model to improve model applicability outside the original dryland areas in the western US. A second meeting in July 2024 discussed the representation of vegetation in the simulations and our efforts to expand the simulation model’s representation from drylands to CONUS-wide characterizations.

Next steps include a follow-up meeting in early 2025 to evaluate and discuss the outcomes of newly developed CONUS-wide vegetation characterizations and to discuss switching from CMIP5-based MACA version 2 (as outlined in the project proposal) to the soon available CMIP6-based MACA version 3 downscaled climate product.

**Results**

1. Synthesizing input data

We completed to preparation and testing of the new NRCS digital soil map product (SOLUS100) for use in our simulations. We double check the appropriate handling of the data with Travis Nauman, the author of SOLUS100.

Veg:

Because the process-based model of soil moisture we utilize in this work explicitly considers the feedback between vegetation and soil moisture, the model must be able to predict characteristics of the vegetation at a given point location based on the meteorological information and soil characteristics that serve as inputs into the model. To this end, we are using statistical models to estimate a series of closed-form equations that indicate the quantity of photosynthetic biomass, the functional composition of vegetation, and the seasonal phenology of biomass accumulation at a given location based on long term climate, recent weather, and soil characteristics.

We have compiled data that we will serve is the predictors in these models, which include soils information from the SOLUS100 product described above, as well as meteorological information from Daymet that has been aggregated into variables that indicate mean climate (values averaged across 30 years) or weather (values averaged across 5 years). We have also generated datasets representing the response variables in these equations. We synthesized data that describe the functional composition of vegetation at a site by combining information from multiple *in-situ* and remotely-sensed data sources, including the US Forest Service Forest Inventory and Analysis dataset (FIA), the LANDFIRE reference database, the Bureau of Land Management Assessment, Inventory, and Monitoring dataset (AIM), and the Rangeland Analysis Platform (RAP). Functional composition is indicated by the absolute percent cover of needle-leaved trees, broad-leaved trees, C3 grasses, C4 grasses, forbs, shrubs, CAM-photosynthesizing species, and bare ground. The plant communities represented in this dataset are broadly distributed both ecologically and geographically across CONUS. We also synthesized a dataset that describes the quantity of biomass at a site, which is broken down into herbaceous biomass, litter (accumulated dead biomass) and the photosynthetic biomass from trees and shrubs. These data come from FIA and RAP. We are also in the process of synthesizing a dataset that describes the seasonal phenology of biomass accumulation using remotely-sensed data. We have begun to fit statistical models that predict the absolute cover of each functional group at a site to climate, weather, and soil characteristics at the corresponding location.

1. Capabilities of the simulation program

Following a decision in the first meeting with the research team and advisory committee, we completed the implementation in the simulation model of the influence of soil organic matter on the soil water retention curve (both for the parametrizations by Campbell and by van Genuchten) and the saturated hydraulic conductivity parameter. The approach follows Lawrence & Slater 2008 as used by other models, e.g., CLM5. It first determines organic matter properties for the soil layers assuming fibric peat characteristics at the soil surface and characteristics of sapric peat at a user-specified depth. Then, bulk soil parameters of the soil water retention curve are estimated as linear combinations of properties for the mineral soil component and of properties for the organic matter soil component using the proportion of organic matter in the bulk soil as weights. The bulk soil saturated hydraulic conductivity parameter accounts for flow pathways through organic matter above a threshold and assumes conductivities through mineral and organic components in series outside of those pathways.

We implemented the capabilities of the simulation program (i) to represent a large set of simulations (e.g., a MACA-based grid across CONUS), (ii) to produce output as netCDFs following the CF conventions using the netcdf-c library, and (iii) to handle unit conversions using the udunits2 library. We also made substantial progress to implement the capability to ingest input data from netCDFs including MACA datasets. Next steps include moving the parallelization from R code directly into the C code of the simulation program and updating the vegetation representation of the model to reflect the new CONUS-wide characterizations.

**Next Steps**

❑ Complete CONUS-wide characterizations of vegetation

❑ Complete implementation of capabilities of the simulation program

❑ Complete synthesizing input data (MACA v2 vs MACA v3)

❑ Execute simulation runs

❑ Verify outputs and drought metrics

**Outreach**

**Budget**