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Predicted 21st century climate variability in southeastern U.S. using downscaled CMIP5 and meta-analysis

Aavudai Anandhi[a,*], Chance Bentley[b]

[a] Biological Systems Engineering, Florida Agricultural and Mechanical University, Tallahassee, FL 32307, USA
[b] College of Agriculture and Food Science, Florida Agricultural and Mechanical University, Tallahassee, FL 32307, USA

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ABSTRACT

Trends and variability of the climate in the southeastern United States, including Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee was studied for an array of future scenarios in the 21st century. The region is a biodiversity hotspot affected by more billion-dollar disasters than any other region in the country. Assessing the impacts of climate change in southeastern United States is important and often requires knowledge of plausible future climate change (e.g. scenarios of temperature and precipitation change). Although several methods are available in literature to develop plausible scenarios of the changes, there exists a usability gap [gap between what scientists understand as useful information and what users recognize as usable]. A novel conceptual framework that represents the plausible future climate change scenarios in southeastern United States was developed using information from meta-analysis and outputs from ~19 Coupled Model Intercomparison Project (CMIP5) Global Climate Models (GCMs) [data analysis] in the form of scenario funnels (represent the plausible trajectories of changes in climate). The systematic literature review provided 33 values of precipitation changes from 15 studies and 35 for temperature changes from 14 studies. In general, the meta-analysis revealed, the precipitation changes observed ranged from −30 to +35% and temperature changes between −2 °C to 6 °C by 2099. Fiftieth percentile of the GCMs predicts no precipitation change and an increase of 2.5 °C temperature in the region by 2099. Among the GCMs, 5th and 95th percentile of precipitation changes range between −40% to 110% and temperature changes between −2 °C to 6 °C by 2099. Finally, the usability of scenario information to stakeholders in various southeastern United States ecosystems and guidelines for developing causal chains and feedback loops with three levels of complexity were provided. They include utilizing the information from impact assessment studies, stakeholder's expertise and requirement as well as understanding the potential impacts in ecosystems (e.g. agroecosystems, coastal, wetland) by relating the structural components of an ecosystem, their interactions with each other, within and across ecosystems for improved management and sustainable use of their resources. These would improve understanding of ecosystem functioning for better management and sustainable use of resources. Although the methodology was demonstrated for southeastern United States, it could also be applicable to other regions of the world. However, the scenario funnels, potential impacts on ecosystems and causal chain/loops are subjective to the study region, availability of literature, the changes observed in the literature and data analyzed, the characteristics of the study region, the stakeholder and their requirement.

1. Introduction

The southeastern United States is a biodiversity hotspot (Cartwright and Wolfe, 2016) with the highest overall native richness of any temperate region in North America (north of Mexico) (Lynch et al., 2016). The region is considered the “wood basket” of the United States, producing about half of the country's timber supply. The southeastern United States is one of the major agricultural areas in the nation. It has an annual output of about $55 billion in agricultural production (about 17% of total annual agricultural production of the USA) and is a major contributor to the US economy (Mitra and Srivastava, 2016). Earlier studies observed, the region produced roughly one quarter of US agricultural crops, and additionally produced a large portion of the nation's fish, poultry, tobacco, oil, coal, and natural gas (Jones et al., 2001).

The southeastern United States receives ample rainfall throughout the year (Rose, 2009). Despite this, the region has experienced recurring droughts that have caused losses in agricultural productivity, prompted water use restrictions on municipal and irrigated waters uses,

* Corresponding author.
E-mail addresses: anandhi@famu.edu (A. Anandhi), chance.bentley@famu.edu (C. Bentley).

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and induced interstate water conflicts (Mitra and Srivastava, 2016). This region is particularly vulnerable to a number of climate-driven events, including sea-level rise and catastrophic floods, drought, heat waves, winter storms, tropical cyclones, and tornadoes (Ingram et al., 2013), and has been affected by more billion-dollar disasters than any other region in the country (Carter et al., 2014). Furthermore, the southeastern United States often suffers from low surface water availability due to frequent occurrences of La Niña, which brings warm and dry conditions between the months of October and April (Mitra and Srivastava, 2016).

Climate change can impact ecosystems in many ways, from effects on species to phenology to wildfire dynamics (Cartwright and Wolfe, 2016). Assessing the potential vulnerability of ecosystems to future changes in climate is an important first step in prioritizing and planning for conservation (Costanza et al., 2016). Additionally, mitigation and adaptation are widely known as the two major responses to climate-driven events (Fu et al., 2016). Scenarios of changes in temperature and precipitation are useful climate information for developing these responses. One way to assess vulnerabilities and impacts, initially through a screening perspective and later with a more directed focus, is to pose plausible and scientifically credible future conditions, or scenarios, with regard to climate variables (Hall et al., 2016). Several methods are available in literature to develop plausible scenarios of changes in near-surface air surface temperature (here called temperature) and precipitation (Anandhi et al., 2008). This study used a novel conceptual framework to develop the scenarios from meta-analysis and data-analysis.

The goal of the study was to provide information to stakeholders while decreasing the usability gap [gap between what scientists understand as useful information and what users recognize as usable in their decision-making (Lemos et al., 2012)]. The specific objectives of this study were to (1) develop a novel conceptual framework that communicates the plausible future climate change scenarios in a region, (2) communicate the potential changes observed in a region (3) develop the causal chain/loops from scenarios and potential impacts for improved ecosystem functioning and informed decision making. The framework was applied to southeastern United States (Fig. 1a). For this the peer-reviewed studies on temperature and precipitation changes in southeastern United States were compiled and synthesized (referred as meta-analysis, Fig. 1b). Also from the Coupled Model Intercomparison Project (CMIP5) downscaled temperature and precipitation data changes were estimated for the region and scenario funnels were developed. Information provided in the scenario funnel is not meant to provide the actual magnitude, along with its timing, of future change; rather, the scenarios are intended to provide a range observed that can assist decision-makers and other stakeholders in making robust choices to manage their risks in the context of plausible future temperature and precipitation changes. The term stakeholders encompass a spectrum of professions and is broadly used to ensure inclusivity as to whom can utilize the methods/results used in this study. The scenario funnel and the data used in developing it would provide a resource for authors of the IPCC Assessment Report and the National Climate Assessment Report (NCA, https://nca2014.globalchange.gov/). NCA is a report submitted to the President and Congress of United States every four years on the status of climate change science and impacts. The NCA informs the nation about already observed changes, the current status of the climate, and anticipated trends for the future by integrating scientific information from multiple sources and sectors to highlight key findings and significant gaps in our knowledge.

2. Methodology

2.1. Definitions/descriptions of key terms

Meta-analysis is a systematic approach to identifying, appraising, synthesizing, and (if appropriate) combining the results of relevant studies to arrive at conclusions about a body of research have been applied with increasing frequency (Stroup et al., 2000). **Snowball sampling** is a tool used in meta-analysis where one accumulates literature sources extracting the relevant references of a known reliable source for use in the analysis, this step may be repeated multiple times until sufficient material is accumulated. **Systems thinking** focuses on understanding the relationships and feedbacks between the parts to understand the entire system (Anandhi, 2017; Caulfield and Maj, 2001), thereby providing a big picture of the system. Global climate models (GCMs) are mathematical formulations of the mechanisms that make up a climactic system (i.e. radiation, energy transfer by winds, formation of clouds, evaporation and precipitation of water, and transport of heat by ocean currents). An **indicator** can be defined as any variable that indicates the magnitude (e.g., mean seasonal temperature) or variability (e.g., standard deviation seasonal rainfall) of a parameter (Alessa et al., 2008), or the statistical relationship among variables (Anandhi, 2017; Gain et al., 2012). **Stakeholders** have been defined as, "individuals or groups with a vested interest in the outcome of a decision" or in the research project (DeLorme et al., 2016). Scenarios represent plausible descriptions of possible future climate states, that must be coherent, internally consistent, and used as planning and communication tools to explore uncertain futures (Berkhout et al., 2002). **Causal chains/loops:** a causal chain is an ordered sequence of events in which any one event in the chain causes the next. When an event in the chain causes an earlier event in the chain then the loop developed is referred to as causal loop. A **scenario** is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold (Mahmoud et al., 2009). The description of scenario funnel is explained in the next section, Fig. 1a and Anandhi et al. (2018).

2.2. Conceptual framework of plausible future climate changes

The future climate is uncertain and unknown, so there can be a full range of possible trajectories of future climate change (Carpenter et al., 2006) often represented using scenarios. The conceptual framework developed in this study (Fig. 1a) combines 1) interpretation to the definition (previous section): scenarios are not forecasts or predictions, but instead, they provide a dynamic view of the future by exploring various trajectories of change that lead to a broadening range of plausible alternative futures in a form of scenario funnel (Mahmoud et al., 2009); 2) a modification of Carpenter et al.'s (2006) framework which was used to explain scenarios for ecosystem services; 3) the concepts of "There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don't know. But there are also unknown unknowns. These are things we do not know we don't know" (Rumsfeld, 2002). In our developed conceptual framework, the possible full and unknown range of trajectories of future climate change is represented by the blue ellipse in Fig. 1a. Many published studies provide some useful ideas about how these trajectories might unfold in future. These studies have based their trajectories on observations from measurements, analysis of historical records, climate model simulations etc. These studies are collected and combined using meta-analysis, to provide a range of trajectories of future climate change represented by the magenta ellipse in Fig. 1a. We have GCM simulation data from virtually the entire international climate modeling community for a range of plausible futures. These GCM simulation data are analyzed to get a range of trajectories of future climate change represented by the green ellipse in Fig. 1a. The meta-analysis can be intended to synthesize the findings of change determined through their evaluation of evidence (confidence) while data-analysis could provide a probabilistic assessment of a variable or its change, or some well-defined outcome having occurred or occurring in the future (likelihood). Together, the circles of data-analysis and meta-analysis represent the information we have access to project the range